UNITED STATES DEPARTMENT OF AGRICULTURE
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FOREST AND RANGE HYDROLOGY HANDBOOK

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FOREWORD

This handbook has been prepared for the manager of Forest lands and rangelands who is responsible for the sustained yield of natural resources from these lands. Whether or not he is consciously aware of it, his work depends to a great extent upon understanding the principles of applied hydrology. This is true not only because water is, in many places, the most valuable of the natural resources, but also because the control of water through intelligent land use is essential to the sustained yield of all other resources as well as to the preservation of the land itself.

The hydrologic behavior of Forest lands and rangelands and the relationship of land use to water yield and streamflow have been studied for many years by the Forest Service Experiment Station personnel. In addition, there are numerous textbooks and other publications on this broad subject. These sources of information were heavily drawn upon in preparing this handbook.

The material in this handbook is arranged in the following principal divisions:

1. Definitions of common hydrologic terms, and a bibliography of textbooks and other publications which present, in detail, many of the subjects briefly referred to in the handbook.

2. A simplified discussion of soil, water, and vegetation (chapters 1 and 2).

3. Procedures for obtaining data required for hydrologic analysis of watershed condition (chapters 3 and 4).

4. Methods and examples for computing the hydrologic effect of land treatment and channel improvements (chapters 5 and 6).

5. Methods of analyzing runoff, erosion, and sedimentation on a watershed basis (chapters 7 and 8).

6. Methods for hydrologic measurements and procedures for the investigation of floods (chapter 9).

DEFINITIONS

1. Antecedent moisture condition refers to the amount of soil moisture at the beginning of a storm.

2. Base flow is part of stream discharge derived from ground-water sources.

3. Basin lag is time difference between center of mass rainfall and resulting runoff.

4. Consumptive use is irrigation terminology for the amount of water used in crop growth including evaporation from the soil (also evapo-transpiration).

5. Design storm is a rainfall depth, area, and time distribution of a given frequency used to estimate runoff for structural design.

6. Direct runoff includes surface runoff, channel precipitation, and subsurface flow during the time associated with the storm event.

7. Drainage area is the watershed draining into a stream at a location.

8. Evapo-transpiration is water used by plants plus evaporation from the soil.

9. Flood is an event where a stream overflows its normal banks.

10. Flood routing determines the changes in a flood wave as it moves downstream through a valley or reservoir.

11. Ground cover is the vegetation and litter which exist on the soil surface.

12. Ground water is water which reaches the zone at saturation (water table).

13. Hydrograph is a chart showing the rise and fall of streamflow during a period of time.

14. Hydrologic cycle is the general circulation of water from the seas to the atmosphere to the ground, and back to the seas again.

15. Hydrology is that branch of physical geography dealing with the waters of the earth with special reference to properties, phenomena, and distribution.

16. Infiltration is the passage of water through the soil surface into the soil.

17. Infiltration capacity is the low rate of water entry into the soil after prolonged wetting.

18. Initial loss is all the rainfall before runoff begins consisting of interception, evaporation, surface detention, and infiltration into soil-water storage.

19. Interception is precipitation retained on plants and finally absorbed or evaporated.

20. Overland flow is water enroute to a channel over the soil surface; upon entering the major channel it may be called surface runoff.

21. Percolation is the movement of water within the soil.

22. Reach is a length of stream or valley, for example between two cross-sections.

23. Regional analysis is a comparison of streamflow and watershed characteristics for gaged streams in the vicinity expressed either graphically or by regression analyses.

24. Soil cover complex is a combination of a soil group and a plant cover type for hydrologic classification or for mapping purposes.

25. Soil group (hydrologic) is a group of soils having similar runoff potential under identical storm and cover conditions.

26. Streamflow is the movement of water under the force of gravity through well-defined semipermanent surface channels.

27. Subsurface flow is water which moves laterally through the upper soil horizons.

28. Surface detention is water in temporary storage as a thin sheet over the soil.

29. Surface retention is that part of precipitation not appearing immediately as infiltration or surface runoff. Includes interception, depression storage, and evaporation during precipitation.

30. Time of concentration is time for water to travel from the most remote part of the basin to the outlet.

31. Transmission loss is a reduction of volume of flow in a stream or canal, due primarily to seepage into the channel bed or banks.

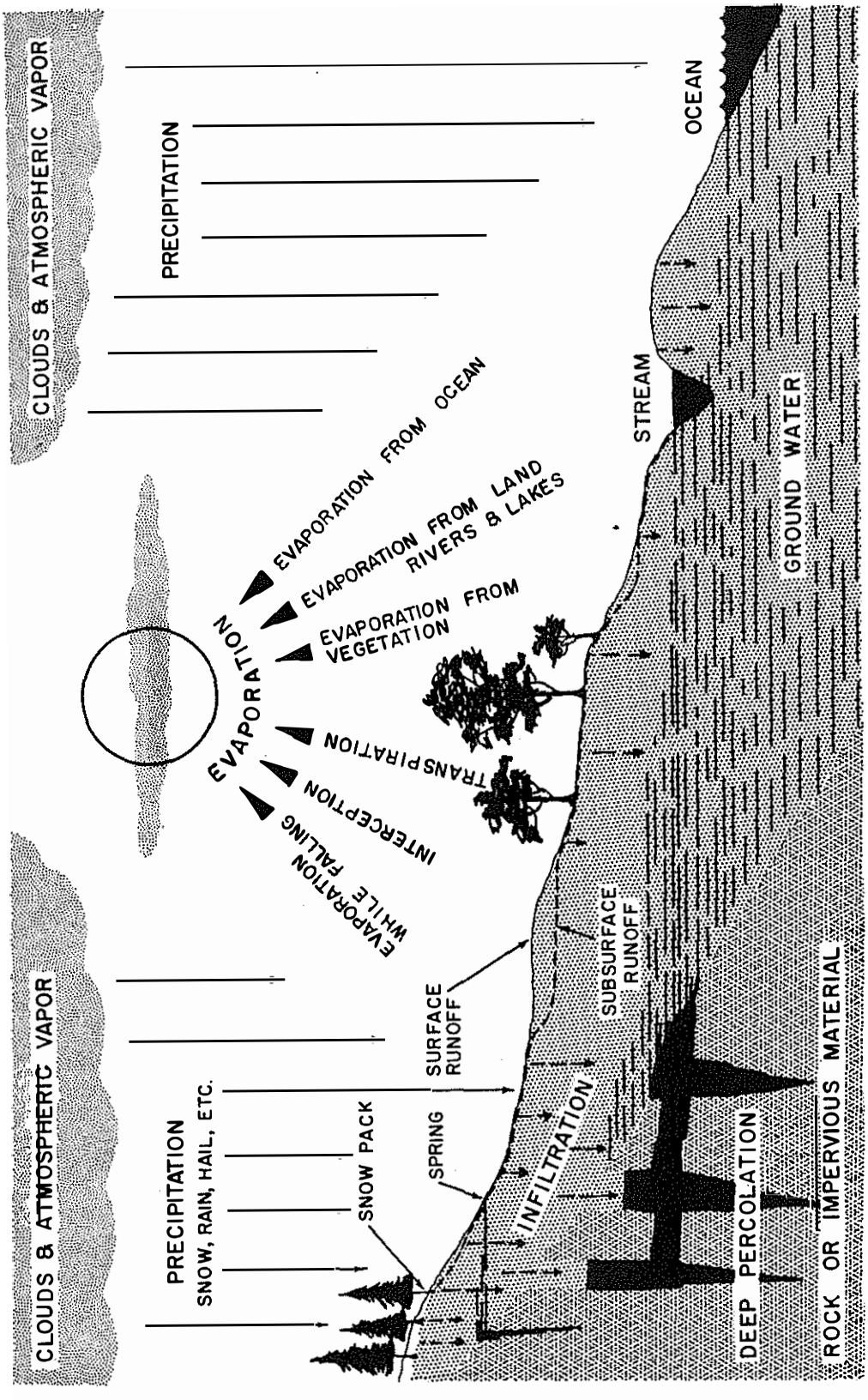
32. Travel time is the average time for water to flow through a length of stream (reach).

33. Unit hydrograph is the discharge from one inch of runoff distributed uniformly over the watershed during a given time.

34. Watershed is the surface area drained by a stream or a fixed body of water and its tributaries.

CONVERSION FACTORS

AF (one foot depth on one acre) = acre foot
c. f. s. (one cubic foot per second) = second foot
In one day: 1 c. f. s. = 1.983 AF
In one year: 1 c. f. s. = 724 AF
In one hour: 1 c. f. s./sq. mi. (csm) = 1.008 c. f. s./acre
One csm/day = 0.03719 inches depth
In one hour: 1 inch/hr = 645.3 c. f. s./sq. mi.
One inch depth = 53.33 AF/sq. mi.
One foot/sec. = 0.6818 mi./hr.
One acre foot (AF) = 43,560 cu. ft.
One sec. foot (c. f. s.) = 0.6463 million gallons/day

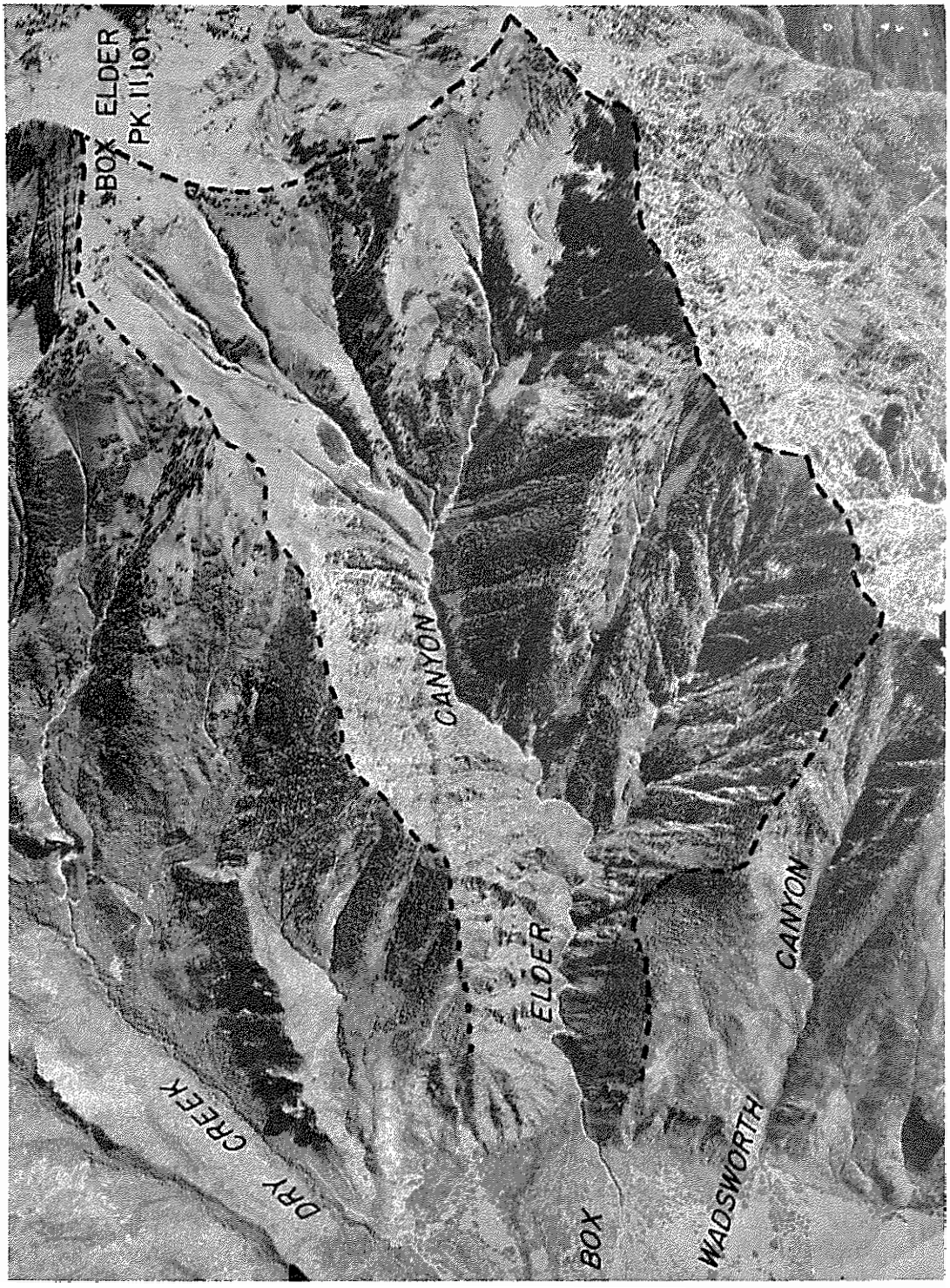


THE HYDROLOGIC CYCLE

(ADAPTED FROM ASCE HYDROLOGY HANDBOOK)

THE WATERSHED

CHAP. 1



CHAPTER 1

1 - WATERSHED

1.1 - Introduction. The drainage area of a stream includes all of the surface area which, by reason of its topography, contributes runoff water to the stream. A large river such as the Mississippi includes within its drainage area a number of tributary streams such as the Missouri, the Ohio, and the Arkansas, each having its own definable drainage areas. Each of these in turn includes a number of smaller streams, etc. The drainage areas of large rivers are called river basins, the drainage areas of smaller streams are commonly called watersheds. The term subwatershed is sometimes applied to tributary drainages within a watershed.

Simply stated, a watershed is a land area having a common outlet for surface runoff. This definition permits delineation of the watershed area on a map. To understand the function of a watershed, however, a third dimension of depth must be recognized. This dimension extends both above and below the land surface to include the cover and climate above the ground and the soil and geologic formations below, as well as the topography and drainage pattern on the surface. In this sense the watershed is a natural reservoir which receives water as precipitation and discharges it as evaporation and transpiration, surface runoff, and deep seepage into ground-water storage.

1.2 - Function as Reservoir. The climate, cover, topography, soil, and substratum of watershed form a natural reservoir which acts in much the same way as a man-made reservoir, to store and control runoff from the watershed. This natural reservoir has a limited storage capacity dependent on the porosity and depth of the soil and rock mantle. When water is supplied to the full reservoir, surface depressions and channel storage hold some of the oversupply temporarily and the excess is discharged as overland flow. The depression storage and overland flow may be likened to spillway storage and discharge in a man-made reservoir. Some water retained in the soil is eventually lost through evaporation and transpiration. As a man-made reservoir is lowered by discharge through the outlet pipe, so the soil reservoir is depleted by downward percolation into the water table and lateral flow into the stream channel. A good forest cover can add to the storage capacity of the soil by adding a surface layer of humus. Forest cover also prolongs runoff time by retarding snowmelt. However, the primary flood control value of the natural reservoir lies in the retardation effect of taking water into the soil and slowly discharging it laterally through the soil into the stream channel.

Capillary water retained in the small soil pores and unavailable for stream flow is like storage in a reservoir full to the spillway. More water can be stored in the reservoir but only temporarily while the spillway is operating. The small soil pores provide retention storage in the

soil, whereas the larger pores provide temporary detention storage.

In mountainous northern regions, watersheds also store winter's precipitation as snow to be melted and released later for irrigation and other uses. This water, or inflow, is also under some form of control, since different amounts and kinds of vegetation will intercept different amounts of snow. The pattern of forest openings may serve to trap, store, and slowly melt greater quantities of snow. Major changes in storage and in melting rates can be made by manipulating the cover. Even after storage in the soil, cover changes involving different root depths may extract different amounts of water for transpiration. Vegetation can add humus, making more storage capacity in or on the soil. Improper land use will reduce this storage or even remove the soil by erosion.

1.3 - Factors Affecting Runoff. The quantity and rate of runoff expresses the combined influence of the natural and cultural features of the watershed from which it comes. Factors affecting runoff are climate, soil, cover, topography, and drainage pattern.

From the following discussion it will be readily apparent that all of these factors are more or less interdependent and influence runoff not only directly but indirectly through their effect upon one or more of the other factors. This interrelationship of influence is more detailed and far reaching than can be described here. A more detailed discussion may be found in the many publications listed in the bibliography. For practical factors used in evaluation see chapters 3 and 4.

1. Climate. Climate is the average condition of weather over a period of years as normally expressed in terms of precipitation, temperature, wind, etc. The general climate of a region; the local climate of a watershed or part of a watershed as induced by aspect, elevation, and vegetal cover; and the microclimate of a site as determined by the soil and cover type, all concern the manager of forest land.

The general climate determines the amount of water supplied to a watershed in the form of rain, snow, sleet, and hail. The intensity, duration, distribution, and direction of storm movement are important factors in determining the ultimate volume and rate of storm runoff.

Local climate may be induced by the aspect, elevation, and vegetal cover of a watershed or part of a watershed. Local climate may vary appreciably from the general climate of the region and may have a pronounced effect on the rate and volume of runoff, particularly from snowmelt.

Within and immediately above the ground cover, a microclimate exists which controls the organic life within the ground cover and thereby affects the development of soil and the water-handling capabilities of the site.

It may be said that the general climate determines the supply of water to a watershed while the local and microclimate affects the water-handling capabilities of the watershed. The local and microclimate are of special concern to the land manager, because they can be changed by manipulation of watershed cover and thereby provide some control over the water-handling capabilities of a watershed.

2. Soil. Soils vary in the quantity of water they will hold and the rate at which water will percolate downward to the water table or laterally to the stream channels. The soil functions as a flood-control reservoir by holding water and releasing it over a period of time. It serves to smooth out the erratic rate of supply from precipitation and release it at a more or less uniform rate as streamflow. Hydrologic analyses are complicated by the large number of soil types which may be found even within a small watershed, and the great variation in their ability to store and transmit water.

3. Cover. Vegetal cover is the product of climate, soil, and topography. Cover determines to a large extent the rate at which water can enter the soil. Cover influences the rate of surface runoff. It influences the depth and distribution of the snow pack, and affects the rate of snowmelt. It influences the loss of water through evaporation and transpiration. It is instrumental in establishing a local or microclimate which may affect the rate and volume of runoff. Over a long period of time it assists in the development of soil.

4. Topography. The elevation, aspect, and slope of a watershed affect the rate of runoff. Elevation affects runoff indirectly through its influence on precipitation, temperature, and vegetal cover. Aspect has a marked effect on vegetation because of variation in exposure to the sun and resultant temperatures. Steepness of slope may influence the velocity of flow. Large mountain ranges serve as climatic divides, interfering with lower air circulation and causing wide variations in precipitation.

5. Drainage Patterns. Drainage patterns have developed over thousands of years as a result of the combined influences of topography, climate, vegetal cover, and soil type. A watershed with a well defined or gullied drainage system tends to produce flashy runoff with high peaks and low minimum flows because the water reaches a stream channel more quickly.

1.4 - Sources of Runoff. All runoff is derived from precipitation. However, the factors affecting the rate of runoff differ appreciably depending on whether the precipitation occurs as rain or snow.

1. Storm Rainfall. While there is always moisture in the air, rising air currents are necessary to produce cooling and condensation of the water vapor which results in precipitation. Convergence of air masses is also necessary to produce heavy precipitation. Based on the

cause of air movement which induces precipitation, rainstorms can be divided into three types: frontal, orographic, and convective.

Frontal storms occur when two airmasses of different temperatures meet. The lighter airmass is forced upward resulting in cooling, condensation, and precipitation. Frontal storms normally produce precipitation of moderate intensity over large areas.

Orographic storms occur when moving, moist airmasses encounter topographic barriers and are forced upward. The lift results in cooling, condensation, and precipitation. The intensity of the resulting precipitation depends upon the abruptness of the change in topography. This type of storm is responsible for the increase of annual precipitation with elevation.

Convective storms result from the heating of the airmasses near the ground by solar radiation. Although convective storms can occur at any time of the year, they are most common and severe during the summer. They do not produce rain over large areas but do produce high intensities, often resulting in floods on small watersheds. The most severe storms of this type, producing high intensities for a short duration over small areas, have been observed in detail at only a few locations. Because they occur over relatively small areas, gage records are usually inadequate to accurately define them. When convective storms occur along abrupt topographic barriers, the orographic lifting may produce rainfall intensities far in excess of those normally associated with either storm type.

2. Snowmelt. In regions where winter precipitation is in the form of snow, the amount which reaches the ground and is stored there until melting is determined by the type and density of the vegetative cover and by the degree of exposure of the area to wind movement. Vegetation, particularly woodlands on exposed sites, reduces wind movement and hence drifting. Vegetation, on the other hand, intercepts snow, thereby reducing the amount reaching the ground. Of all the vegetative types, a forest cover exerts the greatest influence on snow storage. It is a rather common belief that storage can always be increased in a woodland by thinning of the cover. This is not always true, as the factor of site exposure to wind movement may be the determinant as to whether the forest cover will increase or decrease storage. On a windswept site, thinning of the forest cover to any great extent would reduce its effectiveness in the storage of snow. However, when the site is in a protected location where wind movement is at a minimum, the density of the vegetation is the principal determinant of the snow storage capacity of the site. The type of forest cover is also a factor, since evergreens intercept more snow than do deciduous trees which have no leaves during the winter period. As a result, there is a tendency for a greater accumulation of snow under a deciduous forest.

Snowmelt is caused by the application of heat to the snowpack. There are six sources of such heat worthy of consideration. They are (1) heat

stored in the underlying soil, (2) heat in the surrounding air, (3) heat content of rain falling on the snow pack, (4) solar radiation, (5) turbulent exchange of heat from the air, and (6) condensation of atmospheric moisture. The transmission of heat from the soil is small compared to that from other sources, but insofar as it may melt the ground ice, thereby making the ground receptive to melt water from snow, it may be a factor in reducing runoff from snowmelt. Because of the low conductivity of air, the quantity of heat transferred from still air is of minor concern. Rain, being liquid, would have a temperature higher than snow and hence convey heat to it. Contrary to popular opinion, the heat derived from this source is relatively small. The turbulent exchange of heat from the air is one of the most important sources of heat to melt the snow cover. Condensation of atmospheric moisture is likewise an important source of heat. A number of equations have been developed which numerically evaluate the relative effects of the various sources of heat upon snowmelt. Methods for computing snowmelt are discussed in more detail in FSH 3502.

1.5 - Types of Runoff. Runoff can be divided into three types based on the route by which it reaches the stream channel: (1) overland flow, (2) subsurface flow, and (3) ground-water discharge.

Overland flow is runoff water which reaches the stream channel without entering the soil. This type of runoff might logically be called surface runoff, but use of this term by others to denote the total streamflow has confused its meaning.

Water which enters the soil moves in a generally downward direction depending on the character of the soil and underlying rock mantle. Frequently the downward movement of water through the soil is impeded by impervious hardpan or claypan layers which divert the water into lateral flow. In some cases the water may percolate downward to the base of the soil or into the material beneath and then be diverted downslope upon meeting impermeable rock layers through which it cannot pass. A fractured rock structure may produce a similar effect by diverting the water downslope along the lines of fracture. For any of these reasons all or part of the water may be prevented from reaching the water table and is converted to lateral flow to be fed back to the surface as wet weather springs or directly into stream channels. The return to the surface may require days or weeks when the route is long and slow as in a deep mantle, or it may take only minutes or a few hours as on shallow soils underlain by impermeable or slowly permeable layers, when the route is along fracture lines. Water which reaches the stream by one or more of these routes is called subsurface flow. When unimpeded, water tends to percolate downward into the water table and ultimately reappears as springs or directly into the stream channel. This part of the streamflow is called ground-water discharge.

Ground-water discharge and subsurface flow together to make up the bulk of perennial streamflow. Overland flow may in some areas con-

tribute little to the total annual water yield, but is chiefly responsible for sheet and rill erosion and the occurrence of flash floods. When referring to subsurface flow, some writers combine it with overland flow or with ground-water discharge. From a watershed management standpoint, however, these three types of streamflow require separate consideration because they are products of radically different runoff phenomena on the watershed lands and are susceptible to control through watershed treatment in very different degrees of effectiveness. Plant roots and the activities of burrowing creatures associated with vegetation can puncture impeding soil layers and thus improve vertical drainage. Wherever plants occupy the soil, decaying litter is incorporated below the surface, and even small roots that have worked their way through the soil decay and contribute to the development of a microstructure that favors the downward movement of draining water. Vegetation reduces quick subsurface flow through its ability to increase water storage in the soil. Quick subsurface flow cannot be reduced much by the action of vegetation when the soil is underlain with rock or slowly permeable subsoil that offers little opportunity for the entry of water.

1.6 - End Product--Water. This chapter has touched briefly upon the complex interrelationships of the factors which act to affect the rate and volume of runoff from a watershed. For ease of presentation, these factors have been separated into artificial classifications. Actually, no such division exists in nature. It is necessary to keep this in mind to avoid the mistake of seeking or relying upon single-factor solutions to watershed problems no matter how simple the problems or solutions may appear. Practical watershed management can be achieved only to the extent that it rests upon a clear understanding of the fundamental natural processes which govern the behavior of soil, plants, and water.

The objective of watershed management is to meet the problems of land and water use, not in terms of any one resource, but on the basis that all resources are interdependent and must therefore be considered together.

Vegetation acts to reduce the peak loads of streams principally by creating or maintaining a high infiltration capacity, by providing an increase in storage opportunity within the soil for water which would otherwise drain rapidly from it.

Within the natural basic limitations of the watershed, great changes can be made in the rate and volume of runoff by manipulations in vegetative cover. However, changes in cover required to achieve maximum water production may not be compatible with the optimum production and use of other resources. Insofar as cover changes improve and maintain the soil base, other resources may also benefit. Beyond this, cover changes for water production only must be carefully weighed with respect to their effect upon other resources.

The goal of coordinated multiple-use management is not merely the maximum production of all resources present on the watershed. It also includes the relative evaluation of all of the available resources. When necessary, less important resources may need to be subordinated to the maximum production of a more valuable one, but one resource should not be sacrificed merely because of pressure or desire to develop another.

A constant supply of cool, clear water is not the happy byproduct of good management of other resources. Every watershed is a separate problem which must be solved upon its own merits. Political and economic pressures often must be considered. It is important that land managers understand the limitations and possibilities of watershed management for water production so that they do not allow these outside pressures to push them into programs of water management which are incapable of achieving the desired objectives regarding optimum use of all resources available on an individual watershed.

1.7 - Examples

Figure 1.1 - Disposition of Storm Rainfall. This is a schematic diagram for showing what generally happens to rainfall. It is a plotting of depth of water against time (horizontal) from beginning of rainfall.

Starting at the top, the total height of the chart represents the rate of rainfall. Shown first is a small amount of water contributing directly to runoff by falling within the area of the channel--(labeled "channel interception"). The shaded portion of the chart indicates runoff downstream; the unshaded part is retained on the watershed. The case shown is representative of what happens when an intense rainstorm falls on a poor site producing a large amount of surface runoff.

During the early part of the storm the only direct runoff is from the wet channel.

All rainfall up to the time that appreciable runoff reaches a downstream gage is called "initial losses" by some agencies. These losses include interception, evaporation, depression storage, and some soil moisture storage. As shown at the left edge of the chart, the remainder of the rain is disposed of by:

1. Vegetative interception, or water stored on leaves and needles (a very small fraction of an inch). This also includes evaporation from the leaves and transpiration by the plant during the rain (up to perhaps 20 percent of individual small storms in some climates).

2. Depression storage, as tiny ponds which must fill before flow over obstructions will begin. This could be further divided into surface detention if water were assumed to be temporarily stored in a thin sheet over the land, and can also include considerable storage in litter

and humus on the surface or in top horizon. Detention would eventually drain off after rainfall ceased (up to 20 percent of the runoff through dense grass, usually less than 10 percent on bare surfaces).

3. Soil moisture storage comes next when water can pass through the surface of the soil. This water is either retained against gravity in the smaller pores of the soil or temporarily detained in the large pore spaces (noncapillary). Retention storage is high in clay soils and detention is greatest in sands. The detention part of the soil water storage will drain out and contribute to some form of subsurface runoff (20 to 40 percent of soil depth depending on texture, etc.).

Figure 1.2 - Hydrograph of Overland Flow. This graph shows how runoff (Q) gradually flows down the length (L) of a slope (S) as the rainfall (I) continues and detention (D) or storage builds up on the surface.

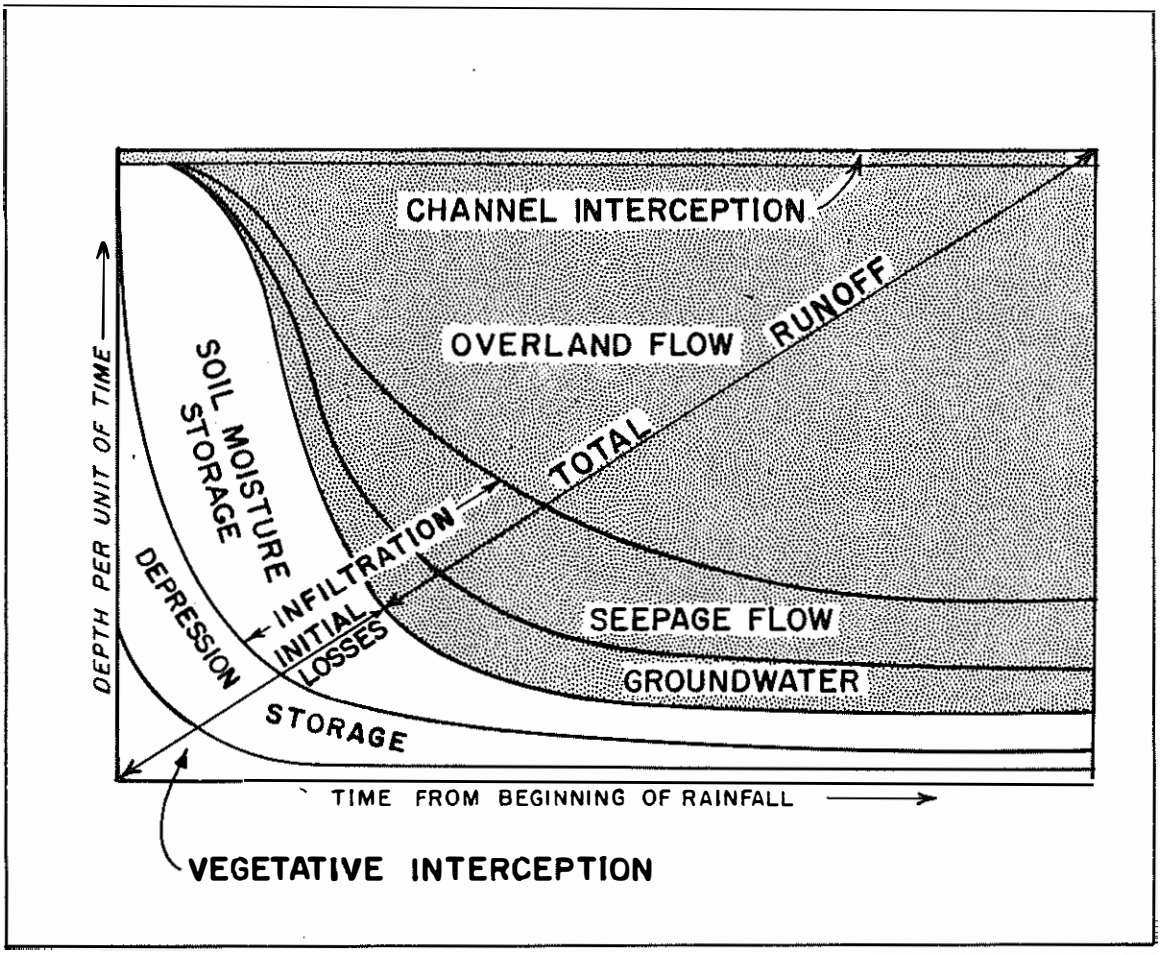


Figure 1.1 - Disposition of Storm Rainfall
(Linsley, R.K. "Applied Hydrology" 1949)

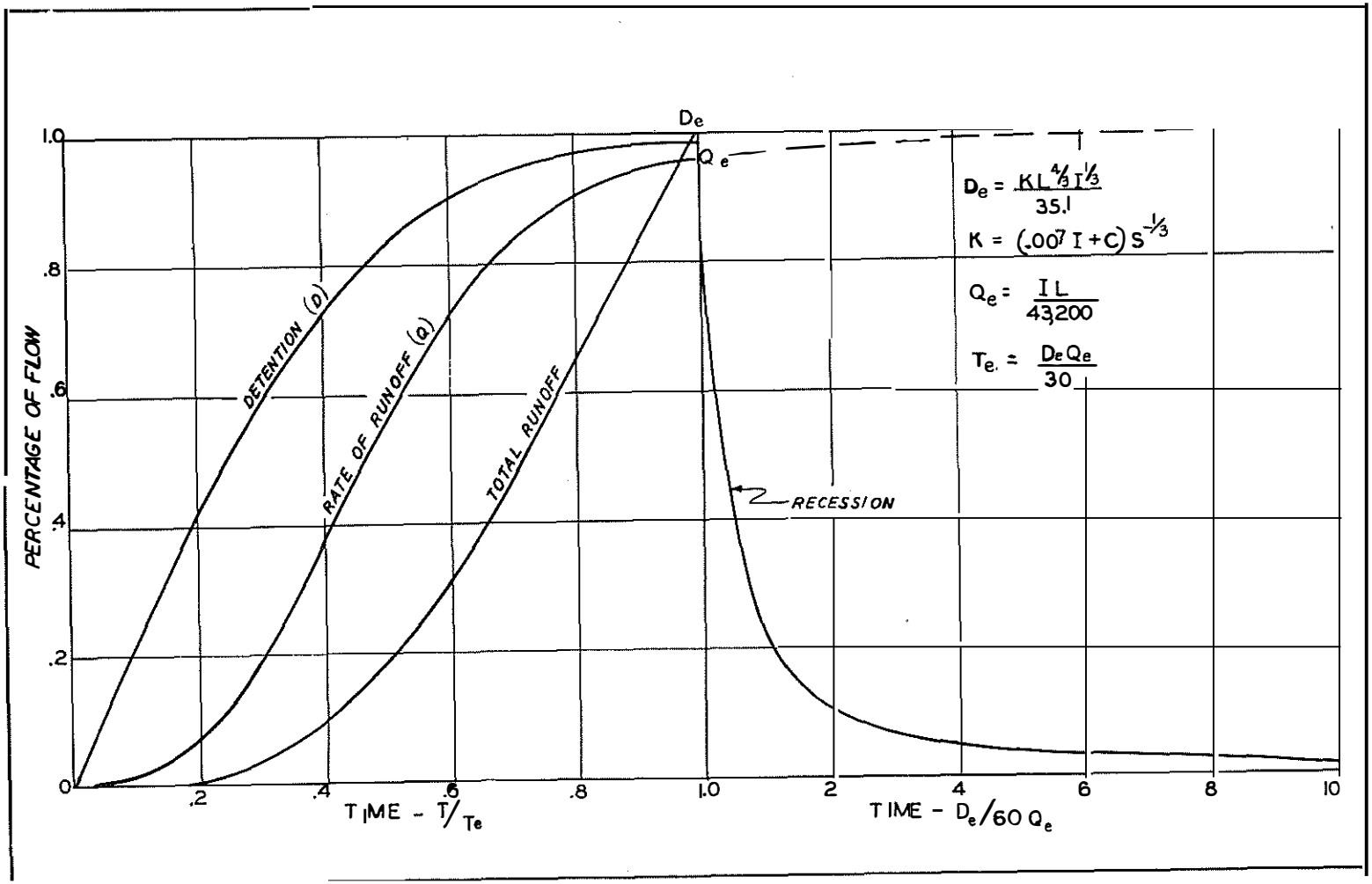


Figure 1.2-Hydrograph of Overland Flow and Recession Curve, (AGU, 1943)

Also shown is the recession of flow as the slope drains after rainfall ceases. The time scale and flow ordinates are merely relative to their totals. The shape of these runoff and recession curves applies generally to small watershed areas; the specific formulas were determined for city lots and airports.

Figure -1.3 - Effect of Length on Overland Flow. The lower part of this graph shows hydographs of overland flow down slopes of various lengths. The runoff from a long slope is slower but lasts longer after the rainfall ceases. A short slope will produce nearly maximum rates after only a short time. The amount of storage remaining on the area as rainfall ceases determines the recession time during which additional water can infiltrate. On a long slope the time and volume of infiltration are much greater than on a short slope. A diagram of this difference is shown at the top of the page for an assumed slope and rainfall condition.

Figure 1.4 - Effect of Slope on Overland Flow. The degree of slope changes the rate of runoff. Steep slopes hold less water in temporary storage and discharge is rapid. The effect of slope varies with rates of rainfall and duration. Slope has little effect during long rainfalls where runoff becomes essentially constant. For the assumed slope conditions shown here, slope markedly influences runoff rates during storms of short duration.

Figure 1.5 - Effect of Vegetation and Soils on Infiltration. This chart is a generalized summary of all infiltration tests in the Intermountain Region in recent years. It shows relative infiltration capacities of various soil and cover conditions to be expected during a rain of long duration after wet antecedent conditions.

The basic infiltration rate of soils is highest for light-textured soils and lowest for heavy soils of shallow depth. Infiltration generally increases with the density of plants and litter, but the change is not great on critical sites. Greater changes can usually be associated with improved ground cover during the ordinary summer storm on dry soils. This chart is for design purposes assuming a potential storm on wet watershed.

Figure 1.6 - Detention Storage in Relation to Soil Depth. Figure 1.6 shows the relation between percolation, infiltration, and detention storage for given conditions. The curves represent the respective cumulative detention storage capacities of three soils to a depth of 30 inches. Infiltration and percolation capacities are shown respectively at the surface and at various depths. By using this curve to trace the disposition of a rain falling at the rate of 1 inch per hour after retention storage has been satisfied, the processes involved will be made clearer.

Curve (1) represents a soil whose detention storage capacity is 2.35 inches, of which 0.65 inch is below the 15-inch depth. The percolation capacity at the 15-inch depth and below is less than the infiltration capacity at the surface. Based on infiltration capacity, the amount of water that would enter the soil is 4 x 0.69 inch or 2.76 inches; the rest of the rainfall, or 1.24 inch, would immediately run off the surface. However, the percolation capacity of 0.05 inch-per hour at the 15-inch level will permit passage of only 0.10 inch of water in the 2-hour period. This amount, plus the 1.69 inches above the 15-inch level, or a total of 1.79 inches, represents the total storage available for the rainwater. This leaves 2.21 inches to surface runoff instead of the 1.24 inch expected when calculated on the basis of infiltration capacity alone.

Rainfall at 1.0"/hr. on Soil at Field Capacity

Depth	1 hr		2 hr.		3 hr.		4 hr.		Runoff
	*S	**O	S	O	S	O	S	O	
	in.	"/hr.	in.	"/hr.	in.	"/hr.	in.	"/hr.	
0"	-	.31	-	.21	-	.31	-	.31	[1] 1.24
6"	.69	-	.11	.58	-	.69	-	.69	-
12"					.02	.67	-	.69	-
18"					.40	.05	-	.69	[2] .87
24"					.05		.05		
30"									

[1] Overland flow
[2] Subsurface flow

*S = Storage, detention in noncapillary pores
**O = Outflow, percolation to next horizon

Curve (2) represents a soil which has greater storage capacity (3.00 inches) than that represented by curve (1). Yet because its infiltration capacity (0.08-inch per hour) is less than the percolation capacity at all horizons, even less of its storage capacity is used than in the previous example. At a rate of 0.08-inch per hour only 0.32 inch of rainfall would enter the soil during the 4-hour rain. The rest, 3.68 inches, would run off. As the storage capacity for this soil is 3.00 inches, 2.68 inches of this space would go unused.

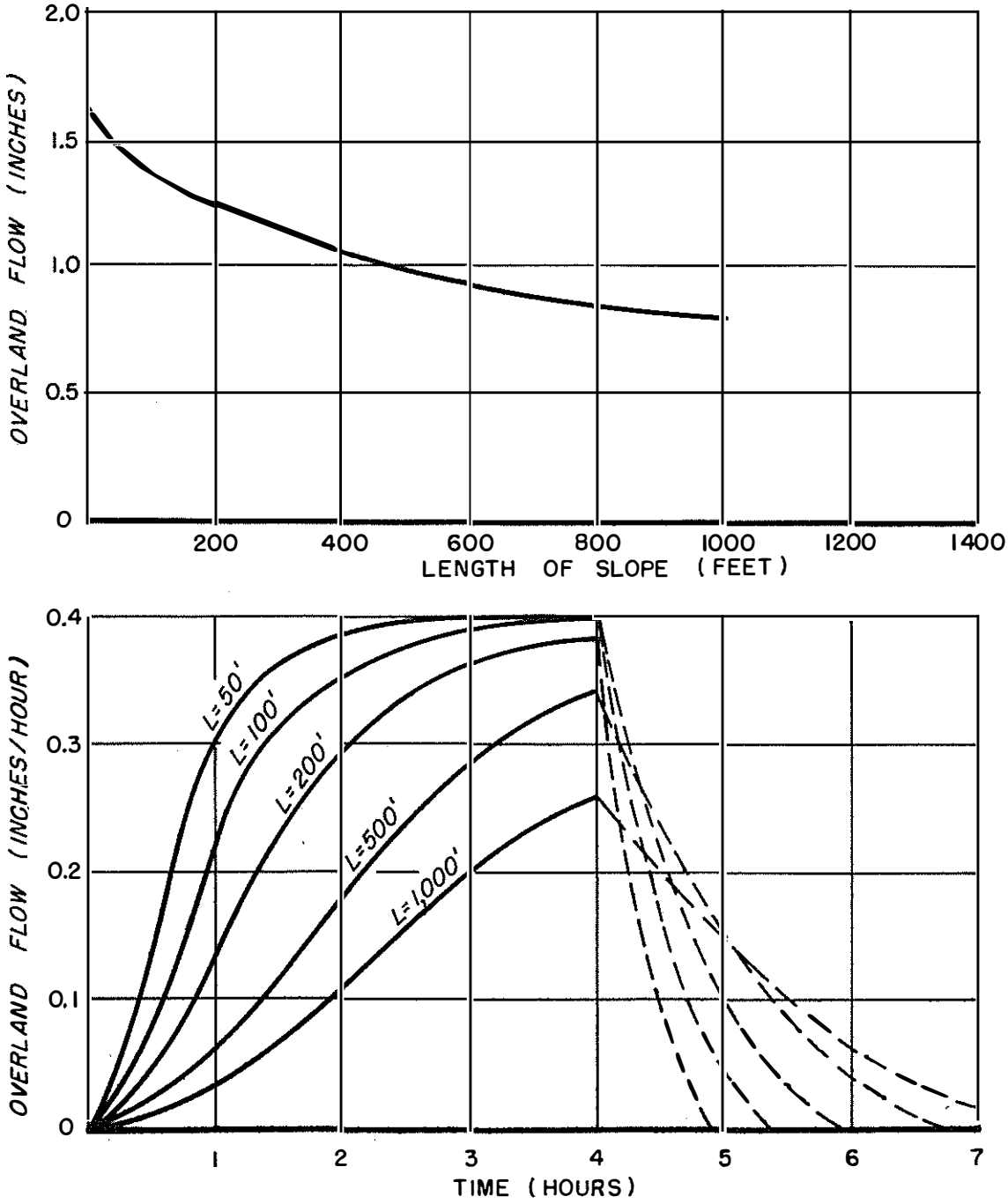


Figure 1.3 - Effect of Length on Overland Flow

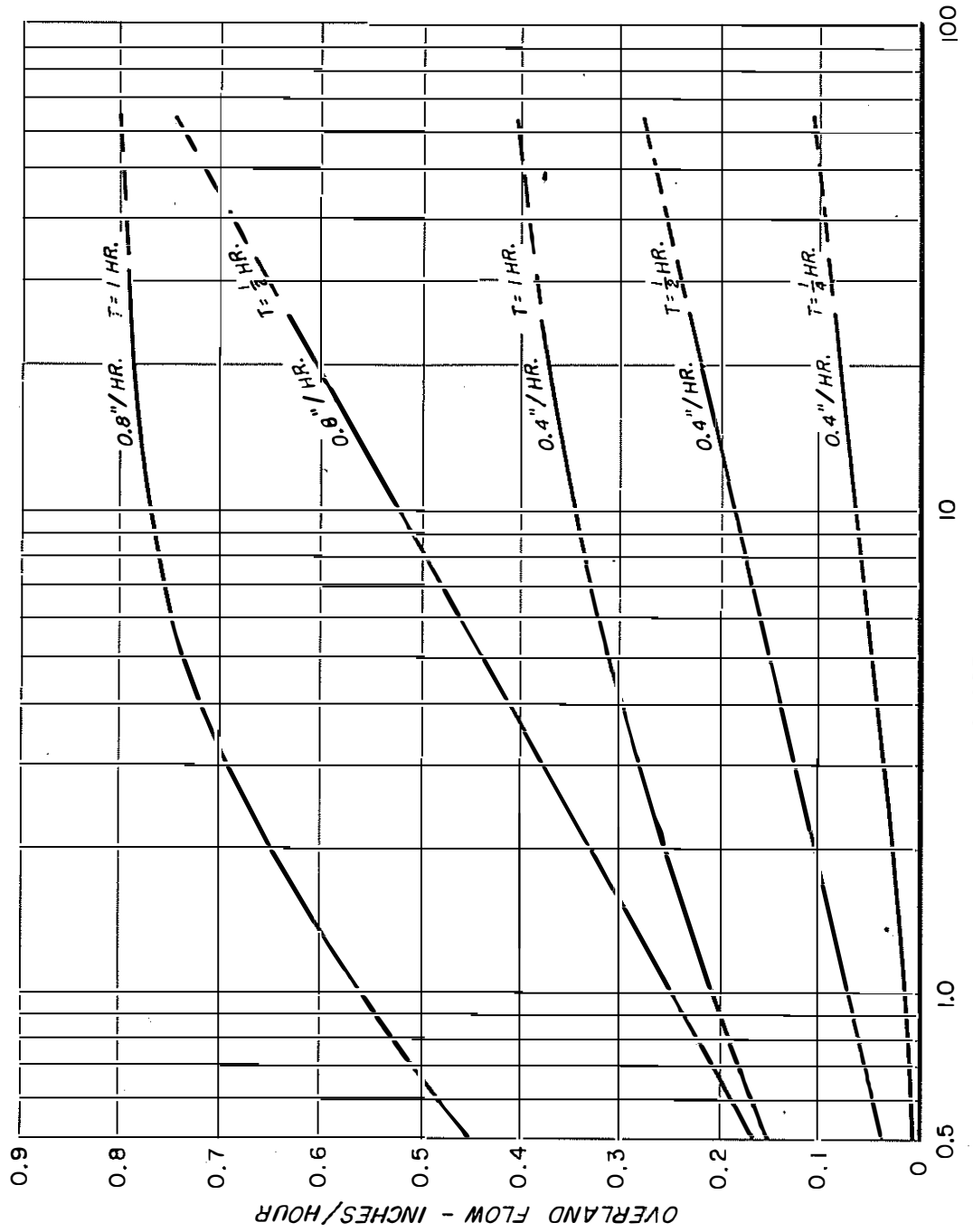


Figure 1.4 - Effect of Slope on Overland Flow

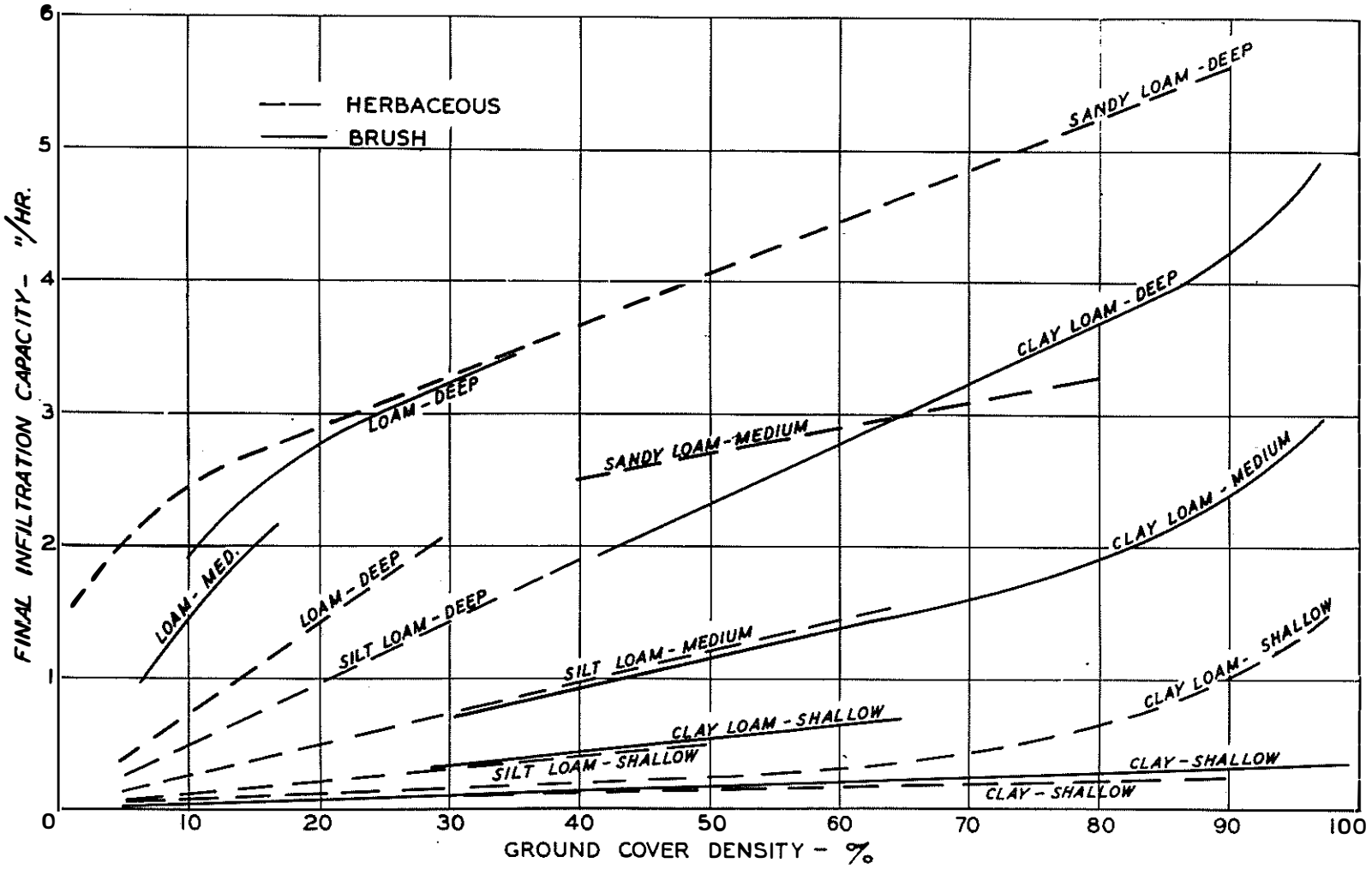


Figure 1.5 - Effect of Vegetation and Soils upon Filtration, Intermtn. Station, 1941-51.

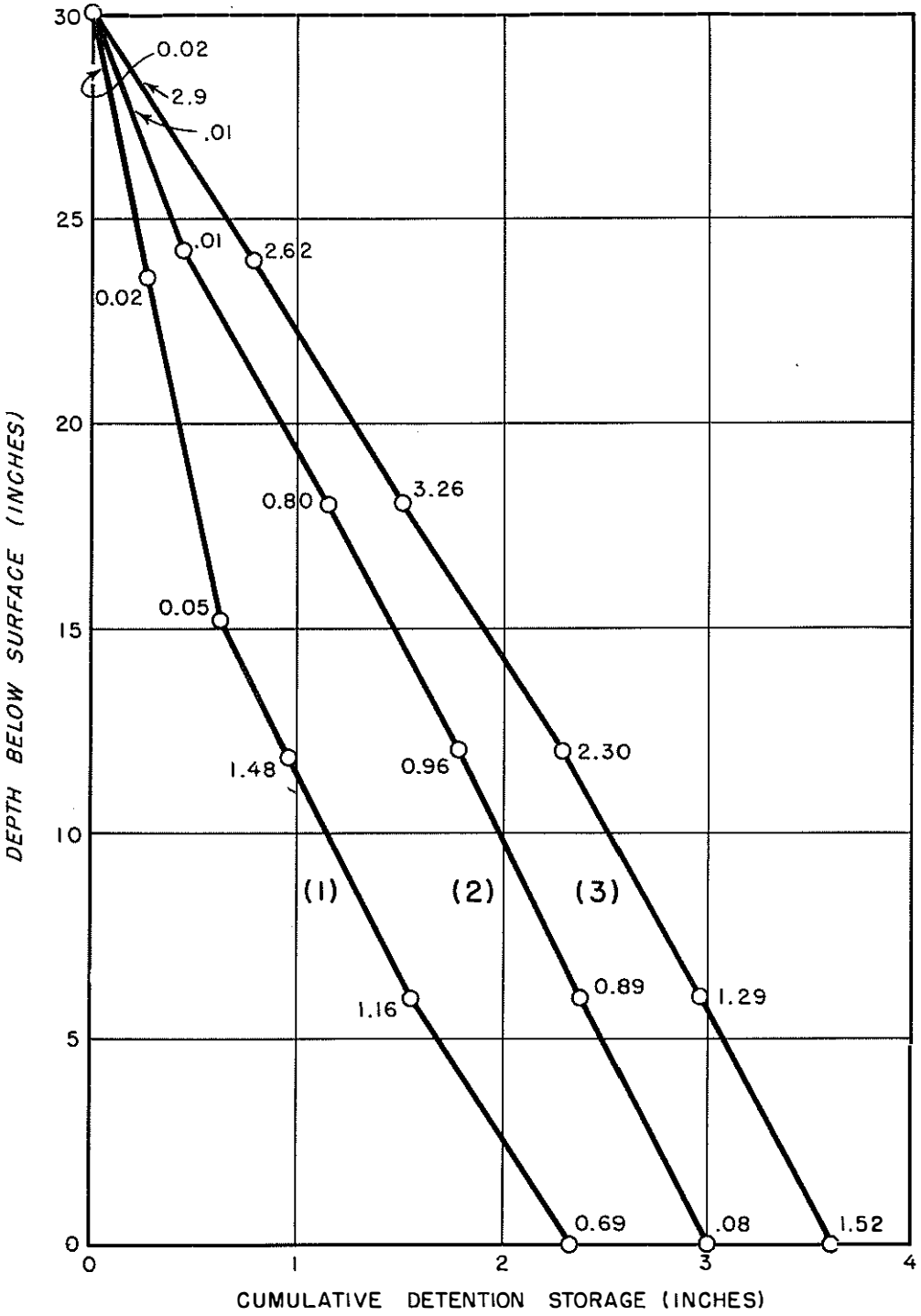


Figure 1.6—Detention storage of three soils in relation to depth. Infiltration capacities at zero depth, and percolation capacities at other depths, are indicated at plotted points.

Rainfall at 1.0"/hr. on Soil at Field Capacity

Depth	1 hr.		2 hr.		3 hr.		4 hr.		Runoff
	*S	O**	S	O	S	O	S	O	
	in.	"/hr.	in.	"/hr.	in.	"/hr.	in.	"/hr.	
0"	-	.92	-	.92	-	.92	-	.92	[1] 3.68
6"	.08	-	.08	-	.08	-	.08	-	

Curve (3) represents a soil with both high infiltration and percolation capacities throughout the 30-inch depth. Since both these capacities exceed the rainfall rate, they impose no limitations upon the rates of water entry and movement. Furthermore, as the storage capacity of the soil mantle is 3.6 inches, the entire rain will be detained. Consequently, no surface runoff will occur.

Rainfall at 1.0"/hr. on Soil at Field Capacity

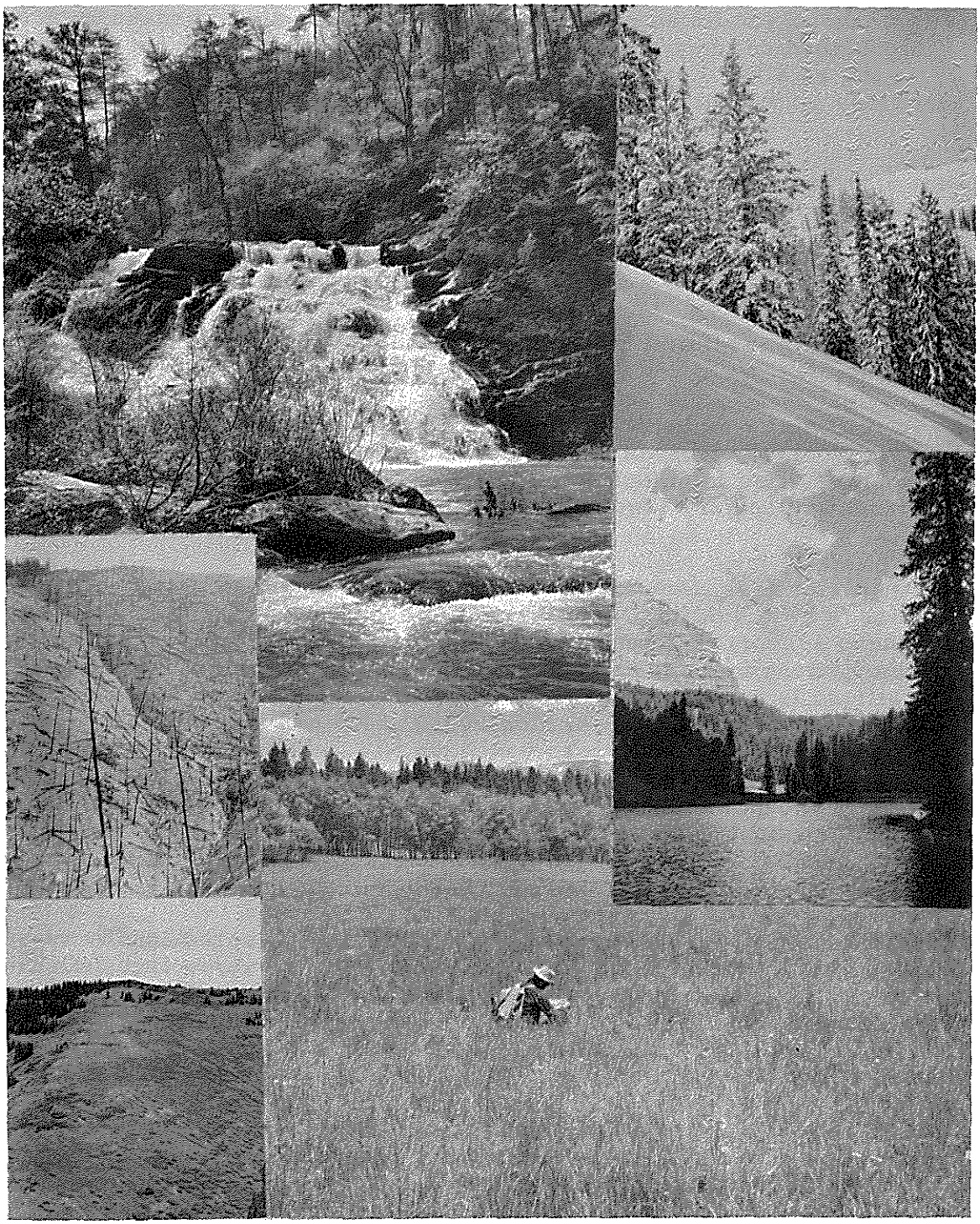
Depth	1 hr. *S	2 hr. S	3 hr. S	4 hr. S	Runoff
	in.	in.	in.	in.	
0"	-	-	-	-	[1] 0.0
6"	.60				
12"	.40	.30			
18"		.70	.10		
24"			.70		
30"			.20	.60	[2] .40

[1] Overland flow
[2] Ground-water recharge

*S = Storage, detention in noncapillary pores
**O = Outflow, percolation to next horizon

FUNCTIONS OF SOILS & COVER

CHAP. 2



CHAPTER 2

2 - FUNCTION OF SOIL AND COVER. Chapter 1 discusses briefly some of the various factors affecting the rate and volume of runoff on a watershed. This chapter presents in more detail the interrelationships between soil and cover and their effect upon the hydrologic processes which water undergoes between the time it falls as precipitation on the watershed and the time it appears in stream channels as runoff.

2.1 - Soil-Water Relationship. The origin and development of soil are beyond the scope of this handbook. However, from a hydrologic standpoint, the amount of water which can be stored in the soil and the processes controlling the supply and depletion of soil water are important considerations in land management.

Soil water may, for convenience, be classified into three types; gravitational, capillary, and hygroscopic:

Hygroscopic water is that portion which is retained as a thin film by the soil particles, after other forms of water have been removed. It is of little interest to the land manager or hydrologist because it is held in place by forces so great that gravitational and surface tension forces will not remove it.

Capillary water occupies the small pores in the soil. It is this form of water which supplies the needs of vegetation. Capillary pore space is particularly important for it represents the retention storage capacity of the soil. Water held in the capillary pores does not directly contribute to stream flow. Various factors influence the amount of capillary water which the soil can hold. Clays hold far greater amounts of capillary water than do sands. The capillary capacity of the soil is also influenced by structure. A compacted sandy soil holds more capillary water than a loose sandy soil. On the other hand, a compacted clay holds less than one with well developed aggregates. Organic matter, because of its highly porous nature, has a pronounced tendency to increase the capillary capacity of coarse-textured soils.

Gravitational water occupies the large or noncapillary pores in the soil. Gravitational water appears in the soil only after the capillary capacity has been satisfied. The noncapillary porosity of the soil is of hydrologic significance because the large pores provide for detention storage of water. This gravitational water is only temporarily detained in the soil. It moves under the force of gravity as opportunity for drainage occurs.

When the gravitational water-storage capacity of the soil is satisfied, the soil is saturated and water can enter the soil after this time only at the rate at which gravitational water drains off and makes room for additional water. This rate is called the minimum infiltration capacity of the soil. Water which is supplied to the saturated soil in

excess of the minimum infiltration capacity rate, must run off as overland flow.

2.2 - Soil-Cover Relationship. Vegetation varies widely in density and form in response to the activities of man and the variations of climate. Uncultivated parts of the country support native or wild vegetation that demonstrates clearly the controlling influence of climate. Despite the great range in form, all types of vegetation show certain characteristics that are important in relation to water-yield control. Every vegetative cover is made up of three parts; the canopy of living and dead stems and leaves that stands clear of the soil, the accumulation of dead and decaying plant remains that lies on or in the soil profile, and the living and dead roots and subsurface stems that permeate the soil.

The canopy above ground and the surface litter accumulation operate as barriers interposed between the atmosphere and the soil. They intercept precipitation, insulate the soil, and retard wind movement near the soil surface. Vegetation at the soil surface obstructs the overland flow of water and the pick-up and transport of soil material. Beneath the soil surface, to depths reached by roots, vegetation acts both directly and indirectly. Roots, by their growth and subsequent death and decay, permeate the soil with material that both binds it and aids the flow of water through it. Roots also absorb water and carry it to the above-ground parts of plants, thus contributing to the return of water to the atmosphere.

Roots may be instrumental in providing avenues for percolation and storage of water in the subsoil by penetrating below the zone of high organic content and increasing noncapillary porosity.

Water serves as a solvent and medium of transport for plant nutrients, and supplies an essential need of all living organisms. Even the richest of soils, as judged by mineral nutrient content, fails to support forests unless the minimum water requirements are satisfied. Conversely, few if any soils are so poor in nutrient elements that they are unable to support forest vegetation when an adequate supply of water is present.

There is an inseparable relationship between soil, cover, and water. While a detailed study of this interrelationship is beyond the scope of this handbook, the following brief discussions of the effects of the various factors will aid in understanding the hydrological processes which water undergoes upon contact with vegetation and soil.

2.3 - Hydrologic Processes Affected by Soil and Cover

2.31 - Interception. In the absence of obstacles, raindrops and snowflakes cover the soil quite uniformly. Vegetation offers obstacles to the free fall of precipitation, which cause changes in the quantity, rate, and time of water delivery to the ground and in the areal

distribution of rain or snow upon the soil surface. Interception of precipitation occurs at two levels within the vegetative cover, in the crown canopy, and in the ground litter.

Because crown cover is seldom complete, some rain and snow falls through openings without touching leaves, branches or stems. Of the precipitation that is caught, some water clings to the crown surfaces, some drops from the canopy, and some flows down stems to the ground. Precipitation which is caught on the crown canopy is exposed to the atmosphere and is therefore subject to evaporation.

This evaporation represents a loss of water so far as water yield is concerned. The remaining water flowing down stems and falling from the canopy causes a redistribution of precipitation reaching the ground. Furthermore, water that drips from the canopy is generally larger than raindrops. If the distance of fall from the canopy to the ground is more than about 25 feet, the drops need be only slightly larger than those of rain in order to exceed its striking force when they hit the ground.

Ground litter operates like the crown canopy, to detain and retain precipitation that reaches it. Litter intercepts water and exposes it to evaporation. Litter causes little if any redistribution of precipitation, and since it lies directly upon the soil it delivers water to the soil as liquid flow and hence without impact. Litter intercepts and reduces the impact of water falling from the canopy, and acts as an insulator against the heat of the soil to delay the melt of snow.

2.32 - Evaporation and Transpiration. The process of evaporation may be defined as a change from the liquid or solid to the gaseous state. Evaporation is a universal process and takes place under all conditions of nature throughout the world. Evaporation supplies all the moisture for precipitation. Losses of water by evaporation on land are not felt greatly in humid or wet climates, since there is generally an excess of moisture to support life. However, in subhumid or arid regions the losses are an important economic factor in the storage of water.

Evaporation may occur wherever there is moisture. Evaporation takes place on the surface of lakes and rivers, on the surface of the soil, and on the surface of leaves of the plants and trees. The lake or river of course, presents a constant supply of moisture. Evaporation of water from the soil surface increases the attractive force there for water, and soil moisture moves up to replenish the surface supply.

Evaporation from a leaf surface increases the attractive force for water in the mesophyll cells of the leaf, and water is drawn into the roots from the soil and upward through the plant stems to the leaf. Depletion of soil moisture by this means is called transpiration.

Evaporation reduces the quantity of water available to plants and transpiration reduces the quantity available for evaporation. Hence, the two processes cannot be considered to operate independently and for practical purposes they can be considered together as affecting the removal of water from the soil.

2.33 - Infiltration. Liquid water that reaches the soil surface moves in one of two directions; downward through the soil surface, or laterally upon it. Downward movement of water through the soil surface is called infiltration. Three forces act to control the rate of infiltration; hydrostatic pressure from above, gravitational pull, and capillary forces from within the soil. Gravitational pull is, of course, constant. The other two forces are variable and subject to influence by vegetation. If water is ponded on the soil surface, hydrostatic pressure is exerted by the weight of the column of water at any point. Capillary force results from the tendency of soil particles to pull water into their surfaces and into the wedge-shaped pore spaces between them. The magnitude of the capillary force is inversely proportional to the size of the pore spaces.

Vegetation acts both at the surface and within the soil to influence the forces controlling infiltration. At the soil surface, vegetation acts to break up the smooth soil surface into one that is rough and pitted. This results in the formation of miniature ponds which create hydrostatic pressure and retard overland flow thereby increasing the time the water is available for infiltration. Accumulations of leaves, twigs, and other plant remains which lie upon the soil are attacked by various organisms and are gradually changed to dark, finely granulated material known as humus. Humus combines directly with fine soil particles to form very stable aggregates. Decomposing organic matter thus aids in the development of highly permeable conditions at the soil surface. This action is carried into the upper layers of the soil by moving organisms which carry with them organic matter upon which they feed. Deep-rooted plants carry this action even more deeply into the soil.

2.34 - Storage and Drainage. As previously stated, water occupies the soil in three forms; hygroscopic, capillary, and gravitational.

Hygroscopic water is of little hydrologic interest because it is tightly held as a thin film around the soil particles and cannot be removed by gravity or capillary force.

Capillary water is held in the small pore spaces of the soil. The volume of these spaces determines the retention storage capacity of the soil. Capillary water is gradually removed as the soil surface is dried by evaporation and the water supply at the surface is replenished by upward movement of water from below. Plants supplement this process by drawing water from the soil and passing it to the air by the process of transpiration. In this manner vegetation removes soil water and enhances the flood control capacity of the soil at the expense of water

yield. This effect is partially offset, however, by the cooling effect of vegetation on the soil surface and the reduction of wind which decreases evaporational losses.

Gravitational water, as the name implies, is drained from the larger pore spaces of the soil by the force of gravity. This drainage may be vertical or laterally downslope, depending upon the uniformity of soil texture and the presence of hardpan layers within the soil mantle. Vegetation may improve the drainage by root penetration of the hardpan layers and by improving the granular structure of the soil. The temporary detention of the gravitational water in the soil reduces flood runoff without affecting water yield.

2.35 - Overland Flow. Precipitation reaching the soil surface, which does not infiltrate or pond in small depressions, moves downhill over the soil surface as overland flow. Rarely does water move over the land as a sheet. Because of surface irregularities, areas of even a few square feet exhibit microdrainage patterns from which water flows downhill merging with other microchannels which merge into rills, gullies, or streams that provide drainage facilities for runoff water. Overland flow is of hydrologic importance for several reasons: it moves quickly to stream channels, thereby causing the flashiest flood peaks; it is only slightly subject to evaporation because of its short time in transit, and sometimes a greater proportion of overland flow than of subsurface flow contributes to streamflow; and it has the capacity by virtue of its velocity to detach soil particles and is therefore an important agent in eroding soil and impairing water quality. The velocity of overland flow largely determines its flood and erosion potential. Water flows more rapidly down steep slopes, over smooth surfaces, and in concentrated channels. Vegetation increases surface roughness, and litter particles on the soil surface form small dams and obstructions which slow down the velocity of overland flow and discourage concentration in rills and gullies.

2.36 - Snow Storage and Melt. Vegetation influences the accumulation of fresh snow by interception and by its effect on wind velocity. Snow intercepted by the crown canopy may be largely returned to the atmosphere by evaporation. Interception therefore represents a reduction in water yield. Vegetation appreciably reduces wind velocity up to the height of the crown canopy and for distances to the leeward as much as twenty times the crown height. The combined effect of the reduction by interception and the increase by reduction in wind velocity may be to increase the depth of accumulated snow above that in the open or reduce it below that in the open, depending on the relative windiness of the site and the density of the forest cover. In general, it may be said that on a windy site a dense forest cover will increase snow storage above that in the open, and on a calm site will reduce it below that in the open. Vegetation generally brings about a redistribution of fallen snow and an unevenness in the depth of accumulation.

Average evaporation losses from snow are appreciably less than from a free water surface, because the snow surface has a maximum temperature of 32° F. and evaporation can take place only when the dewpoint is below 32°. Also the heat required for vaporization is greater at low temperatures, and the increment of vapor pressure per degree decreases so that extremely low dewpoints are required to produce vapor-pressure differences comparable to those experienced in the normal range of summer temperatures. High rates of evaporation may occur when the snow is subject to chinook winds of relatively high temperature and low humidity.

Vegetation retards evaporation by reducing wind velocity, and by the insulating effects of the canopy which shields the snow on the ground from the radiant heat of the sun, and by the ground litter which insulates it against soil heat.

The rate of snowmelt at any location is determined to a great extent by the vegetative influences upon the various sources of heat. It is a matter of common observation that snow disappears more quickly in the open than under a forest cover. The means by which the forest cover retards snowmelt, however, are many and varied. The six noteworthy sources of heat producing snowmelt and the manner in which they are affected by a forest cover are as follows:

1. Heat Stored in Underlying Soil. The ground litter acts as an insulating blanket to protect the snowpack from soil heat. The effect of soil heat on snowmelt is relatively small and the effect of cover on this source of heat is consequently unimportant.

2. Heat in Surrounding Air. Heat is transferred to the snowpack by conduction from the surrounding air. The air in a dense forest cover is cooler during the time of snowmelt than in adjacent open areas. This source of heat from still air is relatively small and unimportant.

3. Heat Content of Rain Falling on Snowpack. It is a matter of common observation that some of the worst spring floods occur following a heavy rainfall on a melting snowpack. Warm rains are accompanied by high humidity and temperature and often by moderate winds, all of which are conducive to rapid snowmelt. When the soil surface is saturated or frozen, a high percentage of the total rainfall runs off as overland flow. A driving rain also acts to break down the snow structure and speed up the release of stored moisture. The rapid runoff may wash unmelted snow into stream channels. These factors combine to produce extremely high rates of runoff. The quantity of snow actually melted by the heat of rain water is relatively small. Vegetation has a deterrent effect on this type of runoff through its influence on local climate, interception of rainfall, prevention of solid ice formation at the soil surface, improvement of infiltration capacity, and the water storage capacity of the litter.

4. Solar Radiation. Direct solar radiation is one of the largest sources of heat-producing snowmelt. Radiation increases with elevation and on high mountain ranges it may be the principal factor in the rate of snowmelt. The interception of radiant heat by the crown cover is perhaps the greatest vegetative influence on snowmelt.

5. Turbulent Exchange of Heat from Air. While the heat transfer from still air is relatively small, a turbulent airmass is capable of transferring large quantities of heat and water vapor to the snowpack. Vegetation influences this convective heat transfer by reducing wind velocity and turbulence.

6. Condensation of Atmospheric Moisture. The transfer of air moisture by turbulent exchange follows the same laws as the transfer of heat from the air. The heat produced by condensation of water vapor on the snow is an important source of heat for snowmelt. Vegetation influences this transfer also by controlling air movement.

2.37 - Erosion and Sedimentation. Erosion is the process by which soil particles are detached from the soil surface. Transportation is the process of moving these detached soil particles to another location. Deposition is the process of dropping these soil particles at a new location. Erosion, transportation, and deposition are natural processes which have sculptured many of the topographic features of our landscape. These processes have been functioning throughout geologic history. This type of normal or geologic erosion is generally beneficial, because it proceeds at a rate slower than that at which new soil is being formed and it helps to keep the soil in a productive condition. This natural balance is easily destroyed by a change in the density or character of the native cover which may result in the accelerated erosion. Control of accelerated erosion is absolutely essential to rational land use.

Erosion is of two general types: sheet erosion and channel erosion. The latter includes rill and gully erosion as well as stream channel erosion.

Sheet erosion is the removal of soil more or less uniformly over the entire soil surface. This type of erosion is not as spectacular as channel erosion and is often not readily apparent to the casual observer. Evidences of sheet erosion are: plants standing with part of the root system exposed indicating that the soil has been washed away around it; soil pedestal; the invasion of plant indicators of a deteriorated soil; and a silt load in streams in the absence of channel erosion. While not as obvious as channel erosion, sheet erosion is probably responsible for damaging a greater land area.

Rill erosion results from scouring of microchannels in which water concentrates as it runs downslope. This type of erosion is more readily recognizable and the rills merge to form gullies which are

almost impossible to overlook. Channel erosion may take place also in streams and rivers as evidenced by bank-cutting and changes in channel alinement.

The relative quantities of soil movement resulting from sheet and channel erosion is highly variable. Generally, sheet erosion is higher in areas of high rainfall, while channel erosion is greater in more arid regions.

The rate of erosion depends upon the length and degree of slope, rainfall intensity, type and density of vegetal cover, and the inherent erodibility of the soil. Erodibility--the tendency of soil to wash away--varies with the soil texture, and the amount of organic matter and colloids in the soil. Both the particles size and the aggregation, or binding together of soil particles, are important. Clay, for example, has very small particles which are easily transported by water but they are not easily detached because of the high aggregation. Sand on the other hand is very easily detached, but is not easily transported because of the larger particle size.

Soil particles may be detached either by the impact of raindrops falling on the bare soil or by water flowing over the soil surface. Although we are interested here primarily in erosion caused by water, it is appropriate to mention that erosion can be caused by wind, which may detach, transport, and deposit soil particles in much the same way as water does, and by gravitational forces which may cause particles or large areas of a hillside to move downslope.

Raindrops striking the bare soil act like miniature bombs to break up soil aggregates and spatter soil particles as much as 2 feet into the air. This spattering effect of rainfall is evidenced by soil deposits on foliage and along the sides of building foundations. Some conception of the striking force of rainfall can be had by consideration of the fact that raindrops strike the ground at velocities of about 30 feet per second, and 1 inch of water over an acre of ground weighs more than 110 tons. Raindrop splash can be an important factor in erosion. This type of erosion can be prevented or reduced by maintenance of a dense ground cover. As mentioned earlier, the effect of a high canopy may be to increase the impact of raindrops striking the ground. It is conceivable, therefore, that a heavily grazed woodland with a high canopy and sparse ground cover might produce more soil erosion than a moderately grazed open pasture.

Water flowing over the soil surface also possesses energy by virtue of its mass and velocity. This energy can be expended upon obstacles in its path. Depending upon how big and well anchored these obstacles are, the water may be slowed down and diverted, or the obstacle may be moved or even picked up and carried downslope. In this way soil particles may be moved or picked up and carried by the flowing water.

The velocity of flowing water is an important factor since the kinetic energy varies as the square of the velocity. If the velocity is doubled, the cutting power is increased 4 times, the quantity of material of a given size that can be carried is increased 32 times, and the volume size of particles that can be carried increases 64 times. Slope is an important factor since velocity varies as the square root of the slope. Water will flow down a 40-percent slope with twice the velocity of that on a 10-percent slope. Vegetation acts to reduce erosion by slowing down the velocity of water flowing over the soil surface. Since erosion is caused by overland flow, the effects of vegetation in reducing and retarding overland flow also operate to reduce erosion.

Erosion and deposition in a stream channel are likewise governed by slope and resultant velocity. This will be discussed in more detail in chapter 6.

It is evident from the above discussions that vegetal cover functions not only to control the rate, volume, and quality of streamflow, but to protect the soil base which supports it.

2.4 - Examples

Figures 2.1 - 2.4. Relation of Overland Flow and Sediment to Ground Cover. Recent infiltrometer tests at the branch stations of the Intermountain Forest and Range Experiment Station have been summarized on the following charts. Data are also shown from larger plots and small watersheds; these relations are similar to those from the small infiltrometer plots.

The effect on runoff and sediment by improving ground cover density can be read from these curves. Extreme values for design purposes are also plotted. Note that overland flow and soil losses drop to low values when the ground cover of plants and litter exceeds about 70-percent density. Observe the range of values measured at different locations in the Intermountain Region.

Figure 2.5.-Consumptive Use of Water. This chart is for the purpose of estimating the evapo-transpiration losses associated with growing plants. Enter the diagram with the monthly temperature and the percent of sunshine, then adjust for the type of crop, considering length of growing season. The final loss should be reduced by the available precipitation, considering overland flow noneffective, and compared with soil moisture storage from the spring months. Evapo-transpiration on the watershed cannot exceed the moisture available from precipitation stored in the soil within the root zone.

From this chart it should be possible to estimate antecedent soil-moisture conditions before a summer storm. Drought conditions affecting plant growth and survival could be rationalized by repeated computations throughout the season. It is intended that the chart be used especially to compare losses of types of vegetation, density of

cover, and the length of growing season by associating the coefficients with experimental determination of consumptive uses by forest and range plants.

Figure 2.6. Factors Affecting Overland Flow. This chart offers a solution to the depth of detention storage and the rate of discharge from watershed slopes. Enter with the rate of rainfall reduced by infiltration and the length of slope to read discharge on the left. Extend the same points to the turning line as part of the next step. Estimate the roughness of the surface on the right, increased for the rate of rainfall, and extend a line through the degree of slope to determine a coefficient. Connect this point with the turning line of the previous step and read the detention in the center of the chart. This volume will be retained on the plot and partly infiltrated during the recession period. Values of detention and discharge can be used to construct unit hydrographs from the typical curves on figure 1.2.

The charts will be a handy way to compare the effectiveness of alternate spacing of terraces, for example, and to design them to hold the runoff from various slopes. Vegetation can also be evaluated by means of a roughness coefficient in retarding runoff and changing detention depths. A separate deduction of infiltration from rainfall should be made before entering the chart(fig. 1.5).

Figure 2.7. Factors Affecting Soil Erosion. This chart makes it possible to estimate how erosion losses will change with various factors. Enter on the chart the annual soil loss as determined by research experiments, or, as a first approximation, based on measurements at the mouth of the watershed, in reservoirs, etc. Ground cover has been conservatively included to the extent of protecting the soil during the growing period of crops when the percent of bare ground is reduced. A higher rainfall rate will increase the erosion, but, of course, is not subject to change except in its frequency for design purposes. A steeper slope will increase the erosion, so will a longer slope. These factors should be compared in designing a terrace system to have equal life before filling with sediment on various slopes.

Finally, research results at Agricultural Experiment Stations have been shown to compare conservation practices on various slopes. This reflects the end product of all the individual influences and can be used to check the calculation. Observations of practices installed and tested on forests and ranges should be added when available from research or flood prevention evaluation studies.

Figure 2.8. Peak Flows and Time of Concentration. Unit hydrograph relations are shown on figure 2.8, sheets 1, 2, & 3. With the size of watershed and estimated time of concentration, peak flows can be read with a straightedge between the two outside lines of the nomograph. Then adjust the peak in proportion to volume of overland flow, since the chart is for one inch of runoff.

Time of concentration can be estimated from figure 2.8, sheet 2, by using the channel length and difference in elevation (average slope of the main channel.) Another equation is shown on figure 2.8, sheet 3, where time of concentration is plotted against drainage area with average slope of the land as a variable. A correction is also made for drainage density (length of minor channel is feet/acre) estimated to be $\pm$ 20 percent for different gully erosion.

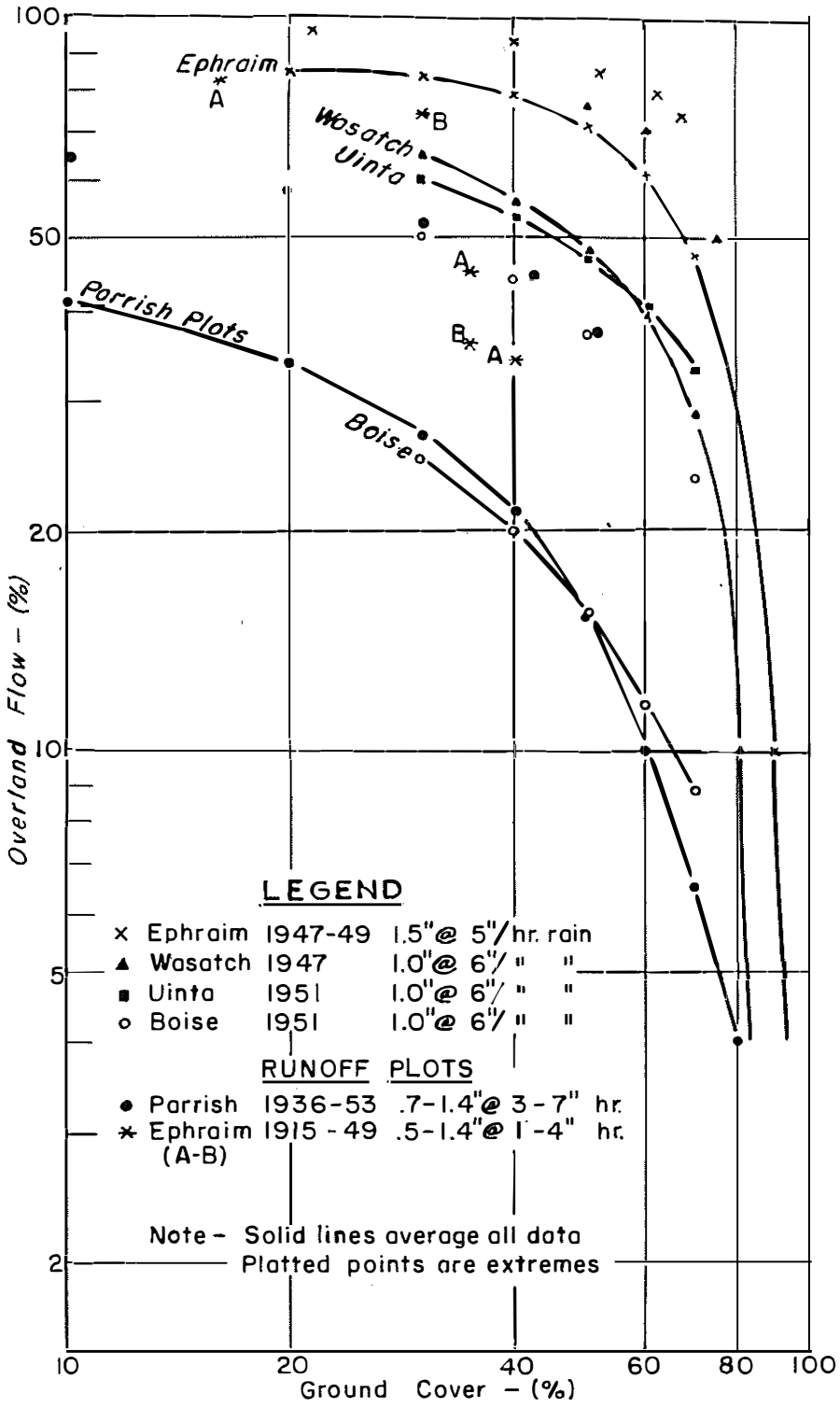


Figure 2.1 – Relation of Overland Flow to Ground Cover
U. S. Forest Service – Intermountain Station

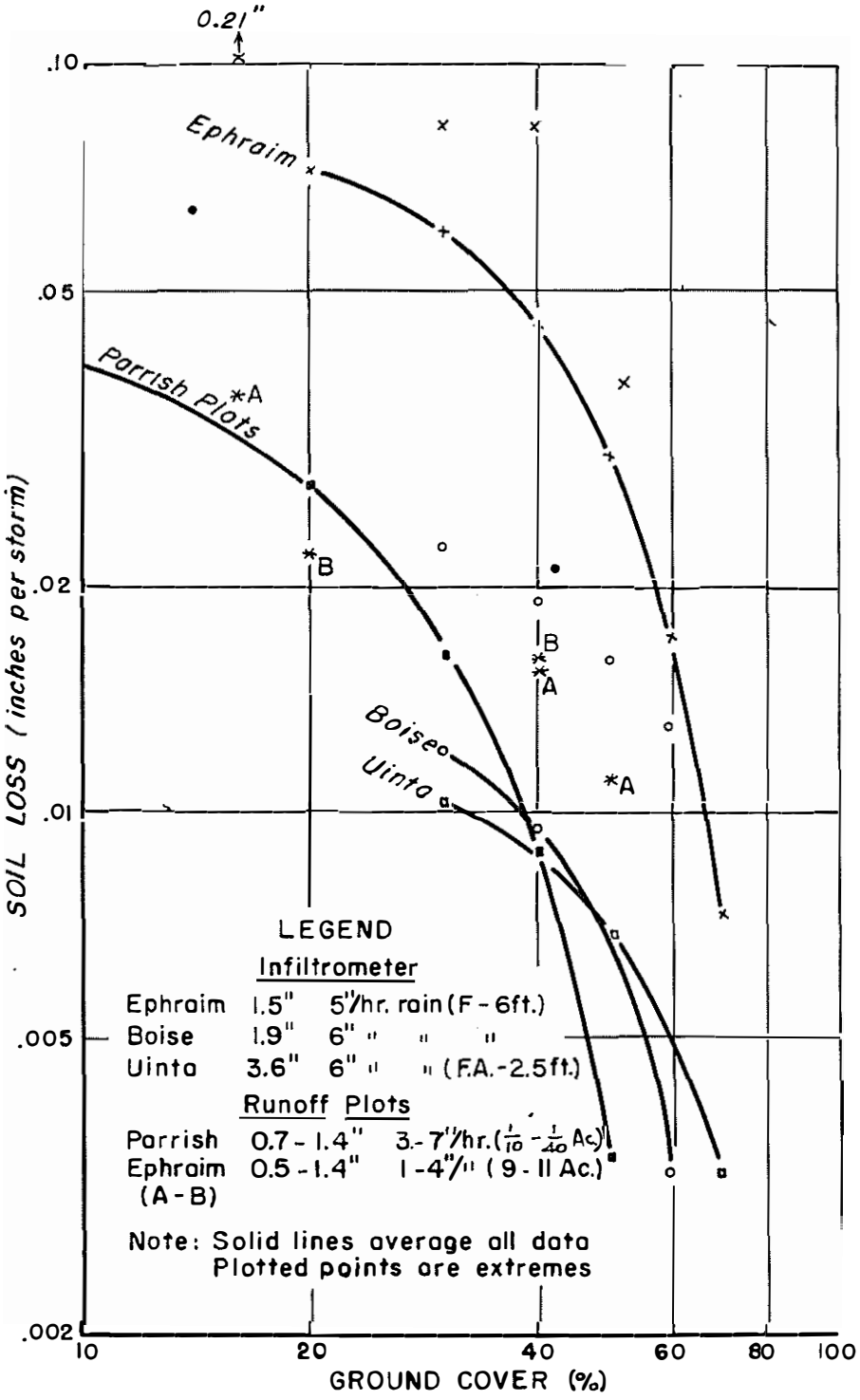


Figure 2.2- Relation of Sediment Eroded to Ground Cover
U.S. Forest Service – Intermountain Station

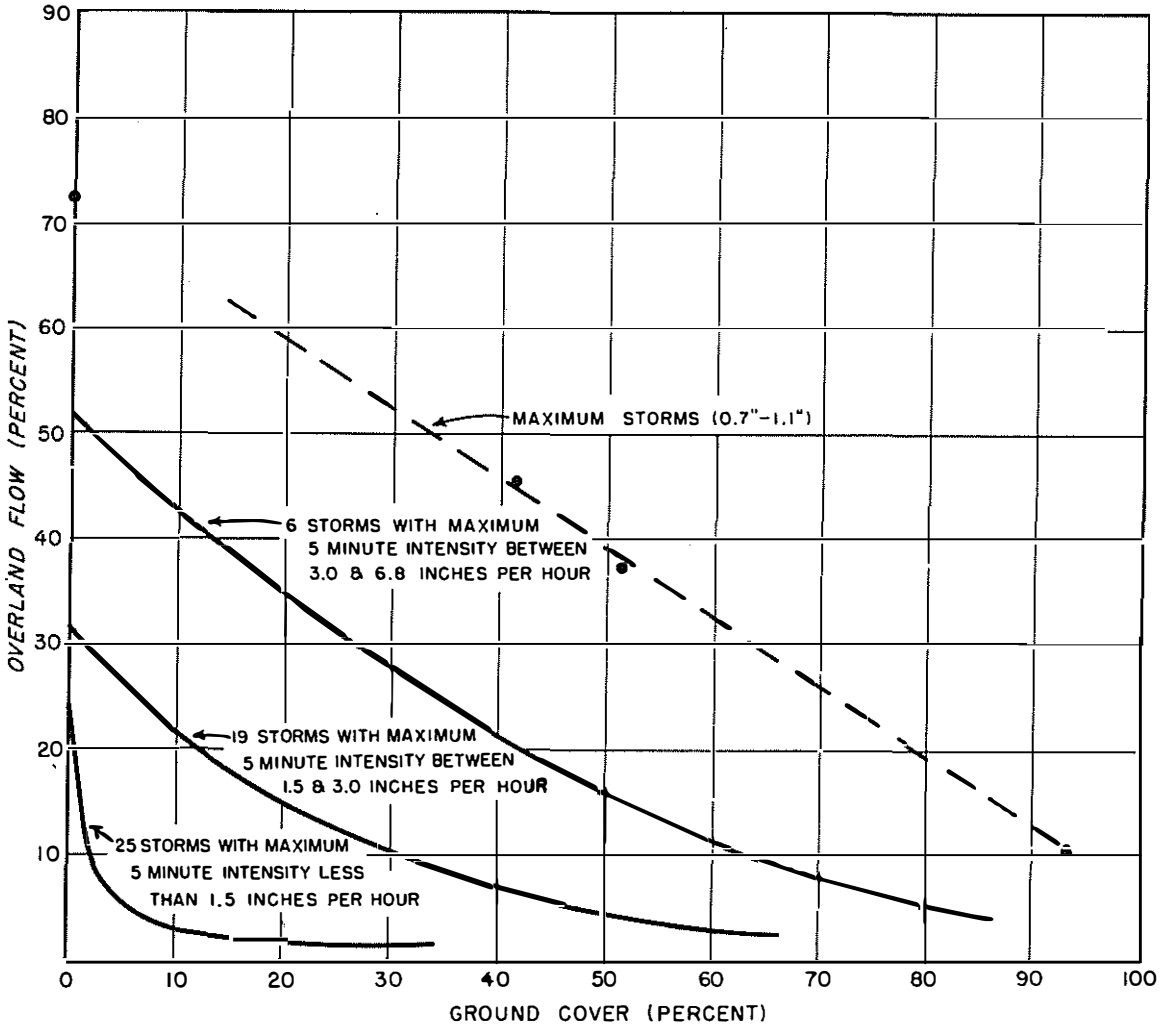


Figure 2.3 – Average relationship of overland flow to total ground cover for storms with high, moderate & low intensities, parrish plots, 1936-53
U. S. Forest Service – Intermountain Station

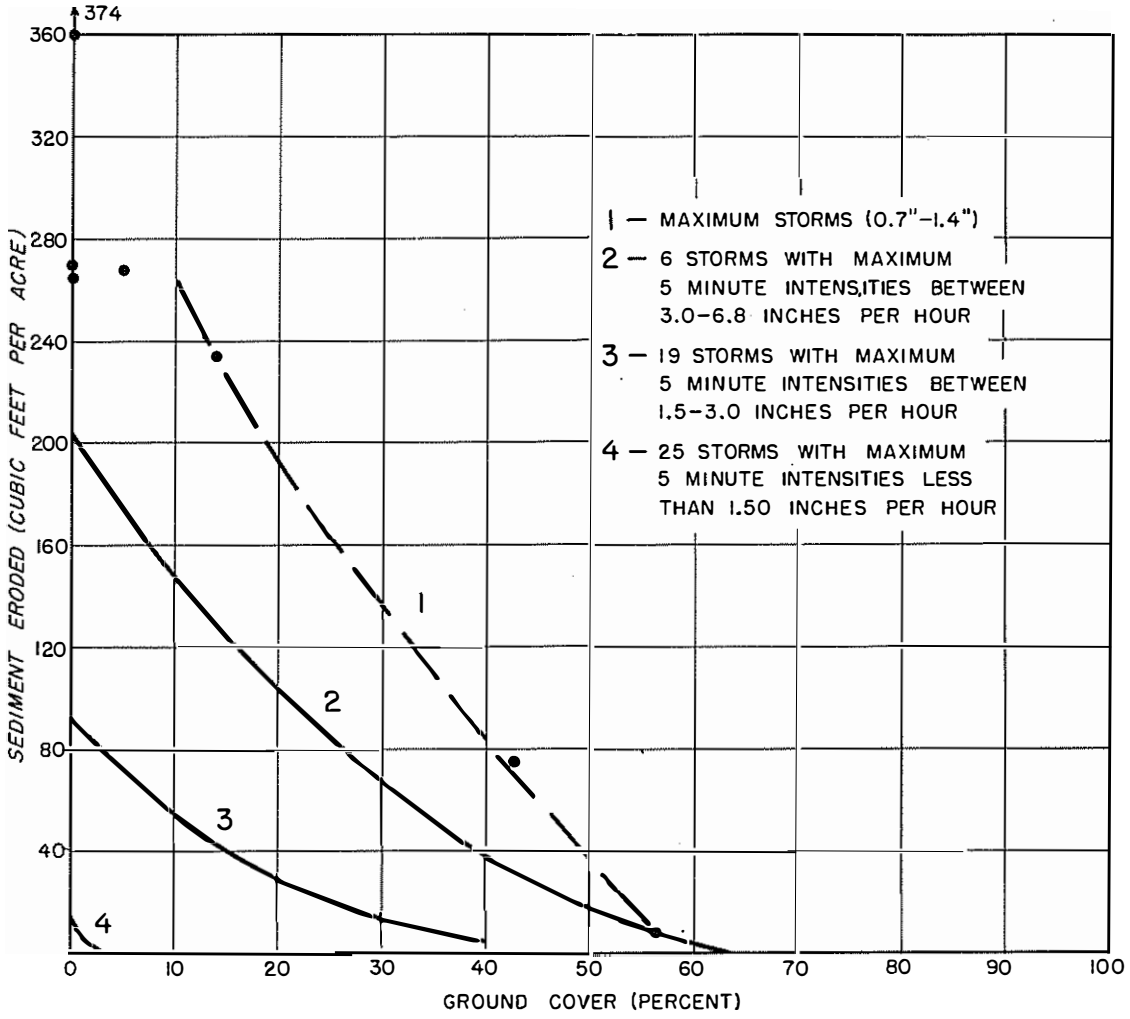


Figure 2.4 — Average relationship of sediment eroded to total ground cover for storms with high, moderate & low intensities, parrish plots, 1936-53
U. S. Forest Service—Intermountain Station

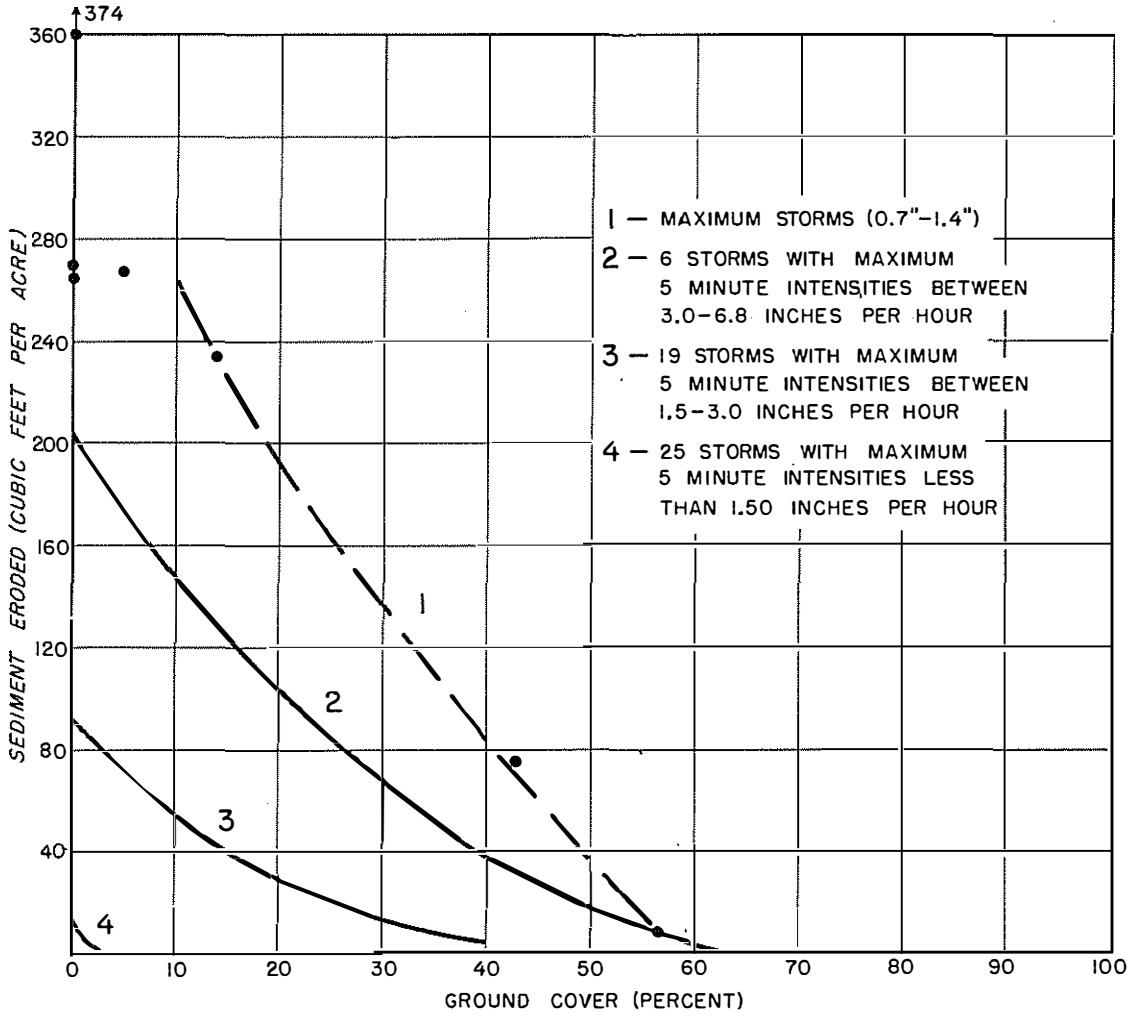


Figure 2.4 — Average relationship of sediment eroded to total ground cover for storms with high, moderate & low intensities, parrish plots, 1936-53
U. S. Forest Service—Intermountain Station

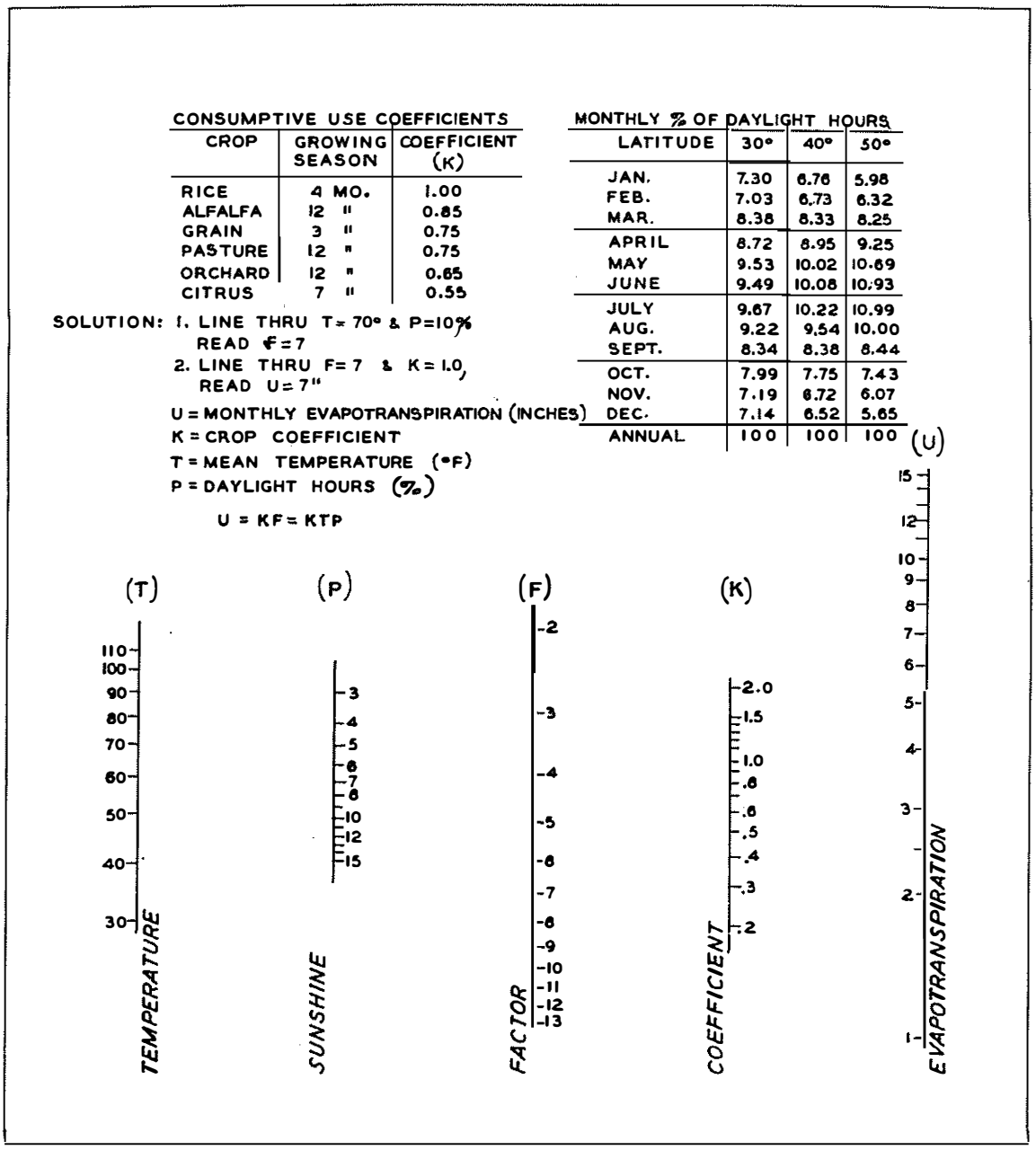

CONSUMPTIVE USE COEFFICIENTS
CROP | GROWING SEASON | COEFFICIENT (K)
RICE | 4 MO. | 1.00
ALFALFA | 12 " | 0.85
GRAIN | 3 " | 0.75
PASTURE | 12 " | 0.75
ORCHARD | 12 " | 0.65
CITRUS | 7 " | 0.55
MONTHLY % OF DAYLIGHT HOURS
LATITUDE | 30° | 40° | 50°
JAN. | 7.30 | 6.76 | 5.98
FEB. | 7.03 | 6.73 | 6.32
MAR. | 8.38 | 8.33 | 8.25
APRIL | 8.72 | 8.95 | 9.25
MAY | 9.53 | 10.02 | 10.69
JUNE | 9.49 | 10.08 | 10.93
JULY | 9.67 | 10.22 | 10.99
AUG. | 9.22 | 9.54 | 10.00
SEPT. | 8.34 | 8.38 | 8.44
OCT. | 7.99 | 7.75 | 7.43
NOV. | 7.19 | 6.72 | 6.07
DEC. | 7.14 | 6.52 | 5.65
ANNUAL | 100 | 100 | 100
SOLUTION: 1. LINE THRU T= 70° & P=10% READ F=7
2. LINE THRU F=7 & K=1.0, READ U=7"
U = MONTHLY EVAPOTRANSPIRATION (INCHES)
K = CROP COEFFICIENT
T = MEAN TEMPERATURE (°F)
P = DAYLIGHT HOURS (%)
U = KF = KTP
(T)
TEMPERATURE
(P)
SUNSHINE
(F)
FACTOR
(K)
COEFFICIENT
(U)
EVAPOTRANSPIRATION

Figure 2.5 - Consumptive Use of Water, SCS, 1953

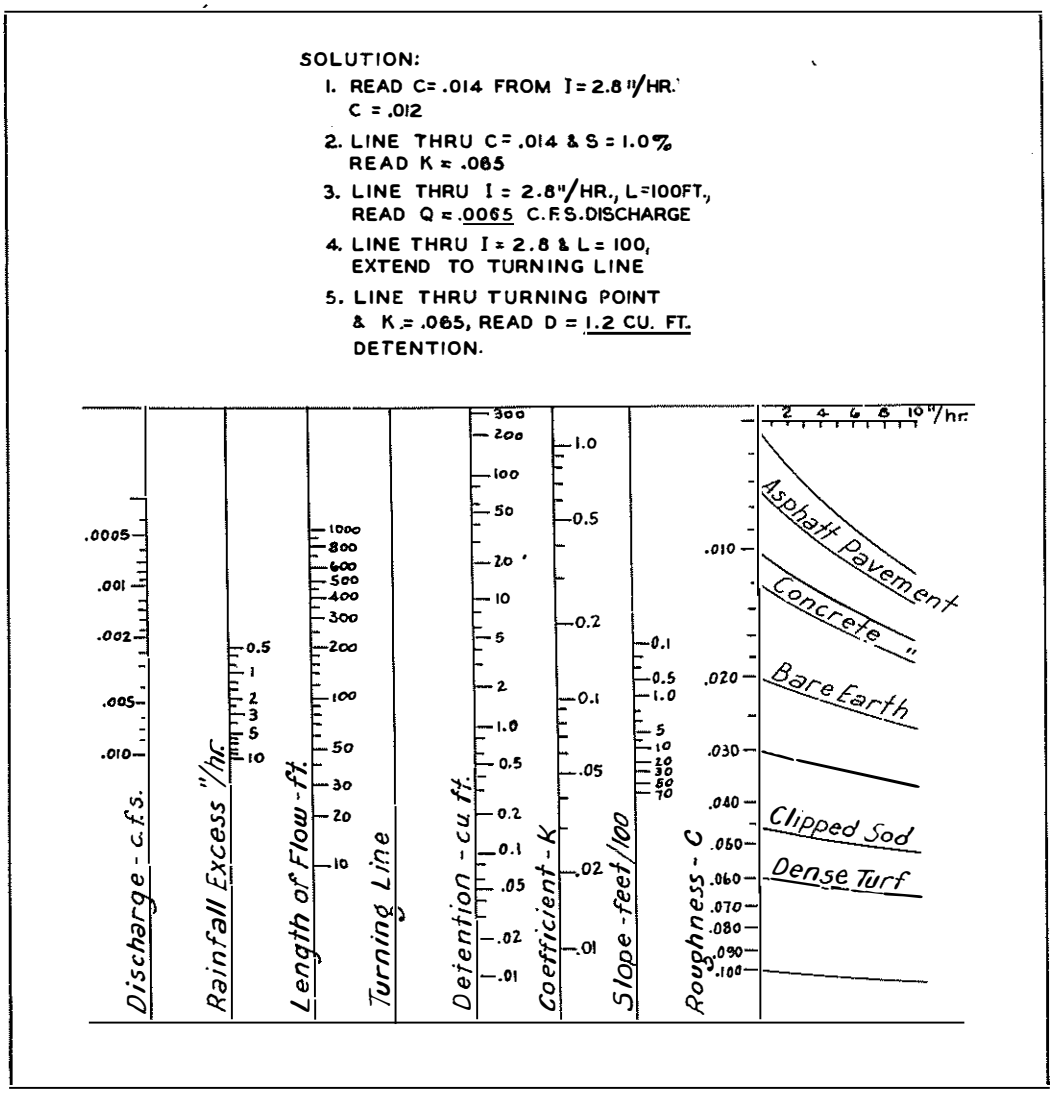

SOLUTION:
1. READ C= .014 FROM I= 2.8 "/HR.
C = .012
2. LINE THRU C= .014 & S = 1.0%
READ K = .065
3. LINE THRU I = 2.8"/HR., L=100FT.,
READ Q = .0065 C.F.S. DISCHARGE
4. LINE THRU I = 2.8 & L = 100,
EXTEND TO TURNING LINE
5. LINE THRU TURNING POINT
& K = .065, READ D = 1.2 CU. FT.
DETENTION.
Discharge - c.f.s.
Rainfall Excess "/hr.
Length of Flow - ft.
Turning Line
Detention - cu ft.
Coefficient - K
Slope - feet/100
Roughness - C
2 4 6 8 10 "/hr.
Asphalt Pavement
Concrete "
Bare Earth
Clipped Sod
Dense Turf

Figure 2.6 – Factors Affecting Overland Flow AGU, 1943

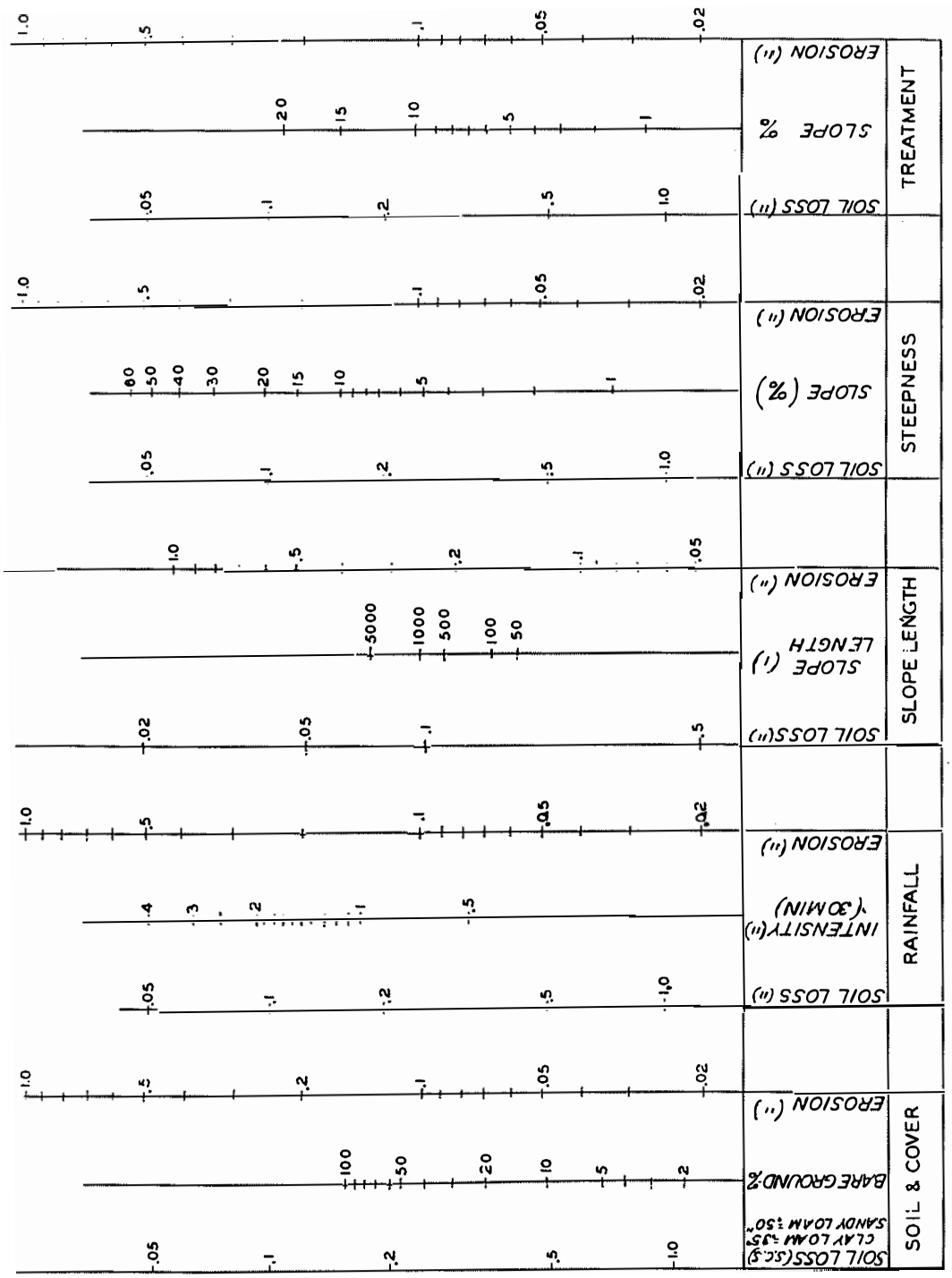


Figure 2.7 - Factors Affecting Soil Erosion, SCS, 1948

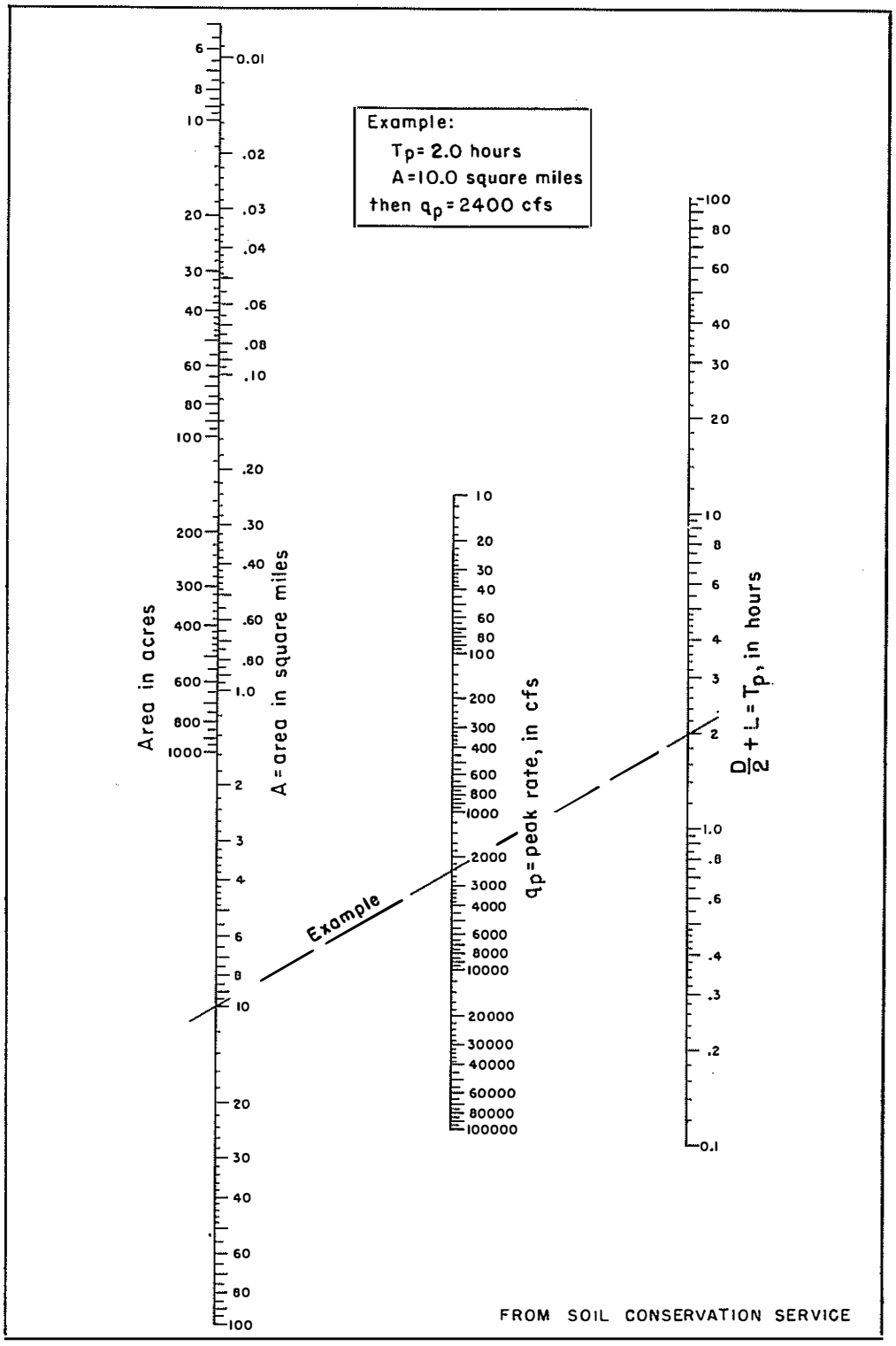


Figure 2.8 (sheet 1) - Hydrology - Peak rates when Q = 1 inch

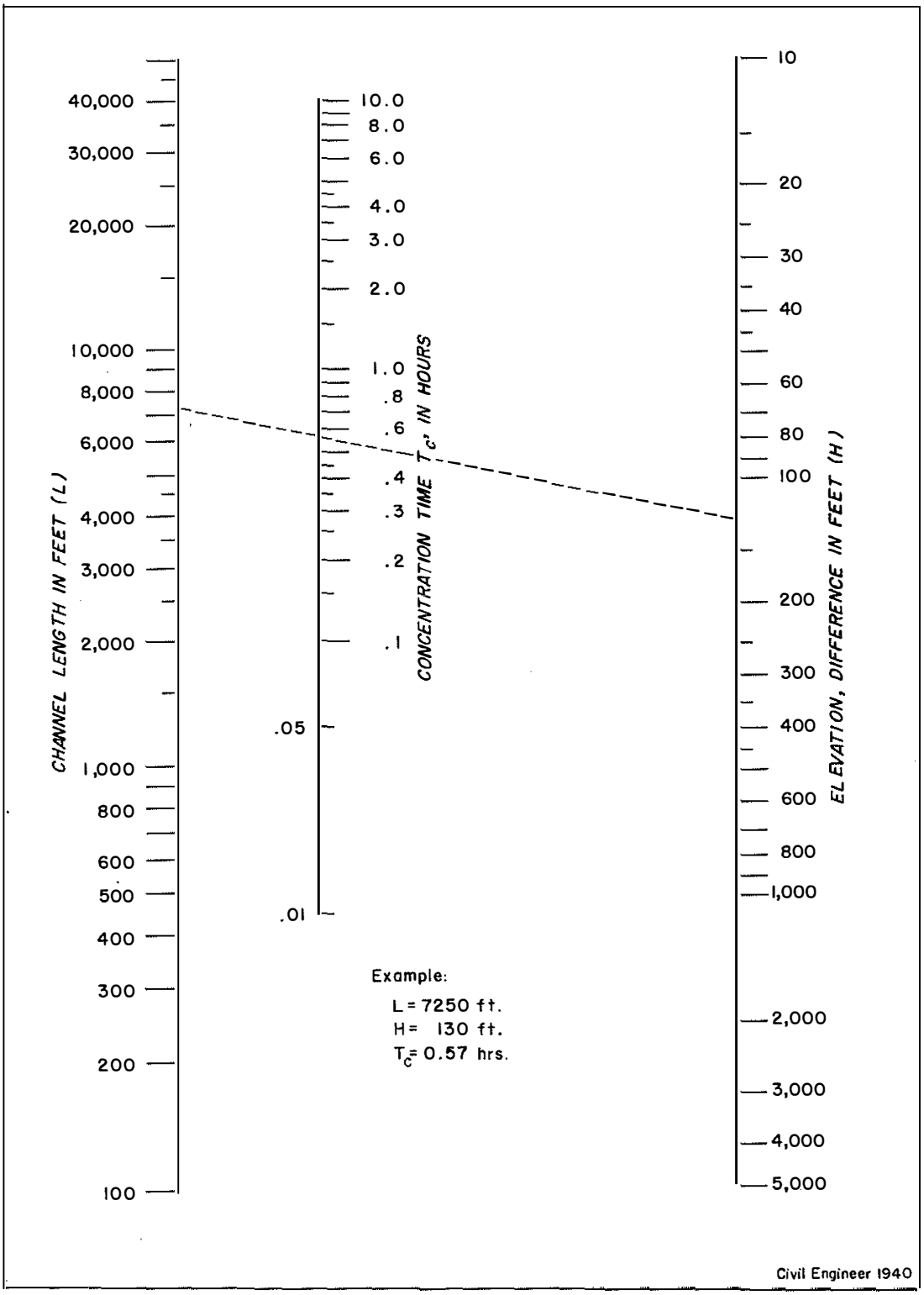


Figure 2.8 (Sheet 2) - Nomograph to Determine Time of Concentration

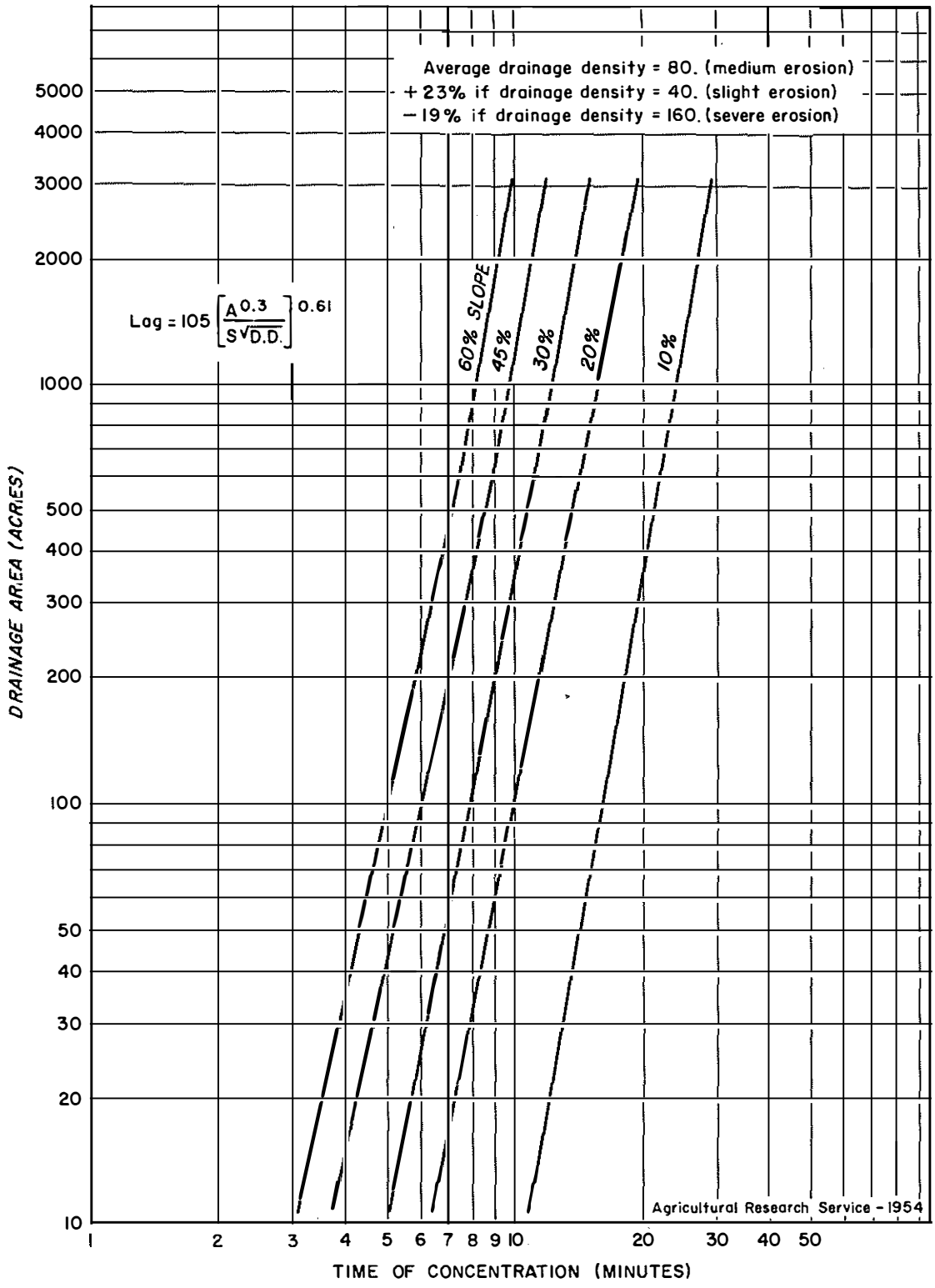
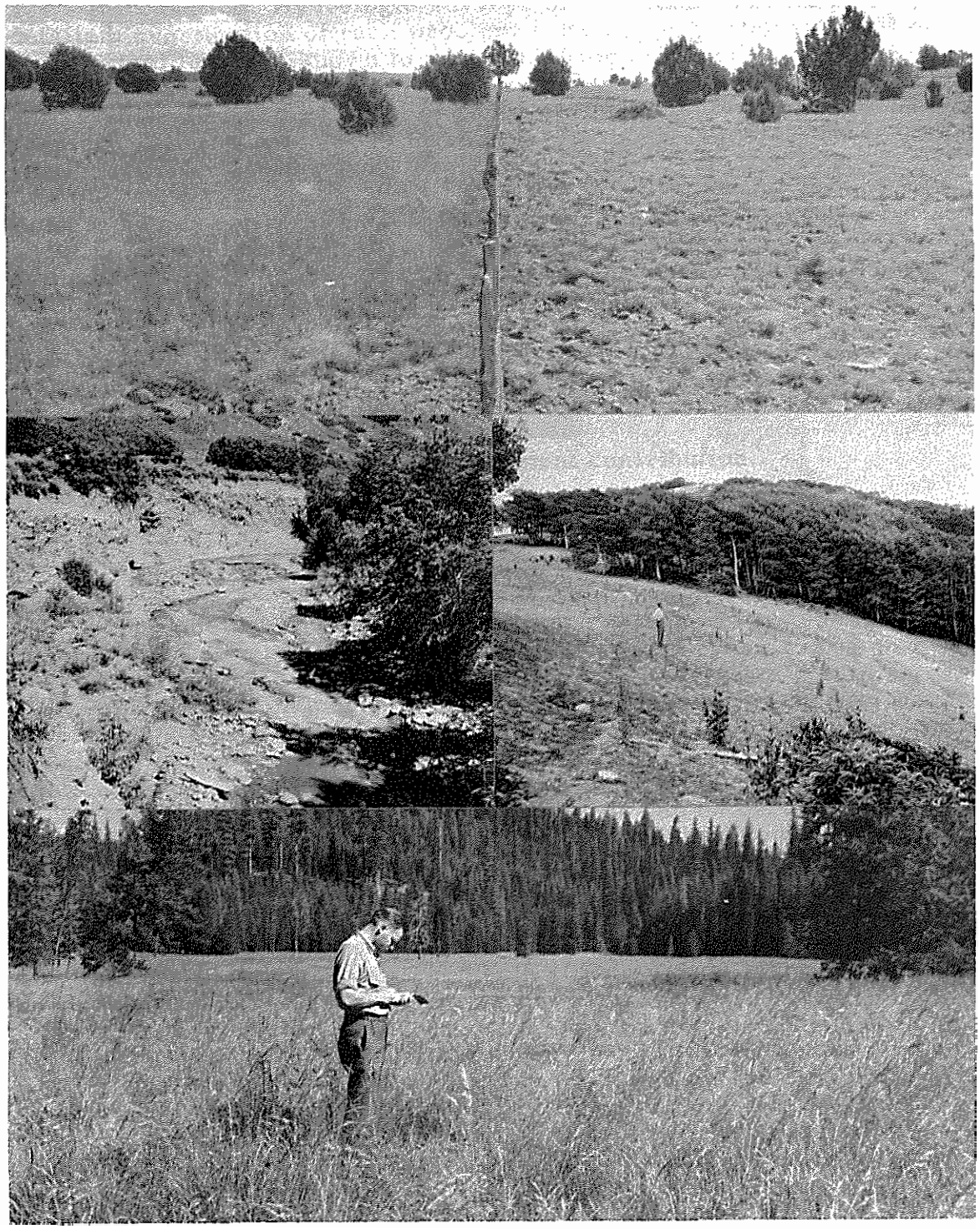


Figure 2.8 (Sheet 3) - Factors Affecting Time of Concentration

RANGE WATERSHED SURVEY METHODS

CHAP. 3



CHAPTER 3

3 - RANGE WATERSHED SURVEY METHODS

3.1 - Introduction. Hydrologic surveys of rangelands should include a detailed investigation of each problem area and an inventory of all of the physical features known to have a bearing on runoff, and erosion. These surveys can be supplemented by more extensive inspection of the entire watershed and by study of range survey data, watershed management plans, project work inventories, timber surveys, and other pertinent material (fig. 3.1).

Each tributary can first be classified by flood and sediment source conditions based on observable differences in surface runoff and erosion characteristics. Several flood and sediment source conditions can be recognized as follows:

1. Low surface runoff and sediment contribution.

2. Moderate surface runoff and sediment contribution.

3. High surface runoff and sediment contribution.

4. High seepage runoff and sediment contribution.

5. Low seepage runoff and sediment contribution.

Each problem area is subdivided into slope and aspect phases in order to isolate the effects of these physical features on runoff, erosion, cover condition, and on the feasibility of various types of treatment. The slope classes include: (a) slopes ranging in steepness from 0 to 10 percent, (b) slopes 10 to 30 percent, (c) slopes 30 to 60 percent and (d) slopes 60 percent or over. The aspects recognized are north, south, east, and west. These observations are recorded on a form such as illustrated by table 3.1. Whenever IBM cards can be used, they are a very effective means of recording and analyzing field data. See table 3.2, sheets 1 and 2.

Several soil characteristics can also be recognized on the problem areas, all of which are known to have some bearing on runoff, erosion, and watershed management. The depth of the surface soil can be recorded by one-inch classes, also depth to impervious stratum, or total estimated depth of root zone. The soils are further classified by standard texture classes and according to the parent material from which they were derived. The parent materials included the igneous and metamorphic formations, and the sedimentaries. Erosion conditions can also be recognized, including both sheet and gully erosion. The former is classed as slight, moderate, and severe and the latter as occasional to frequent.

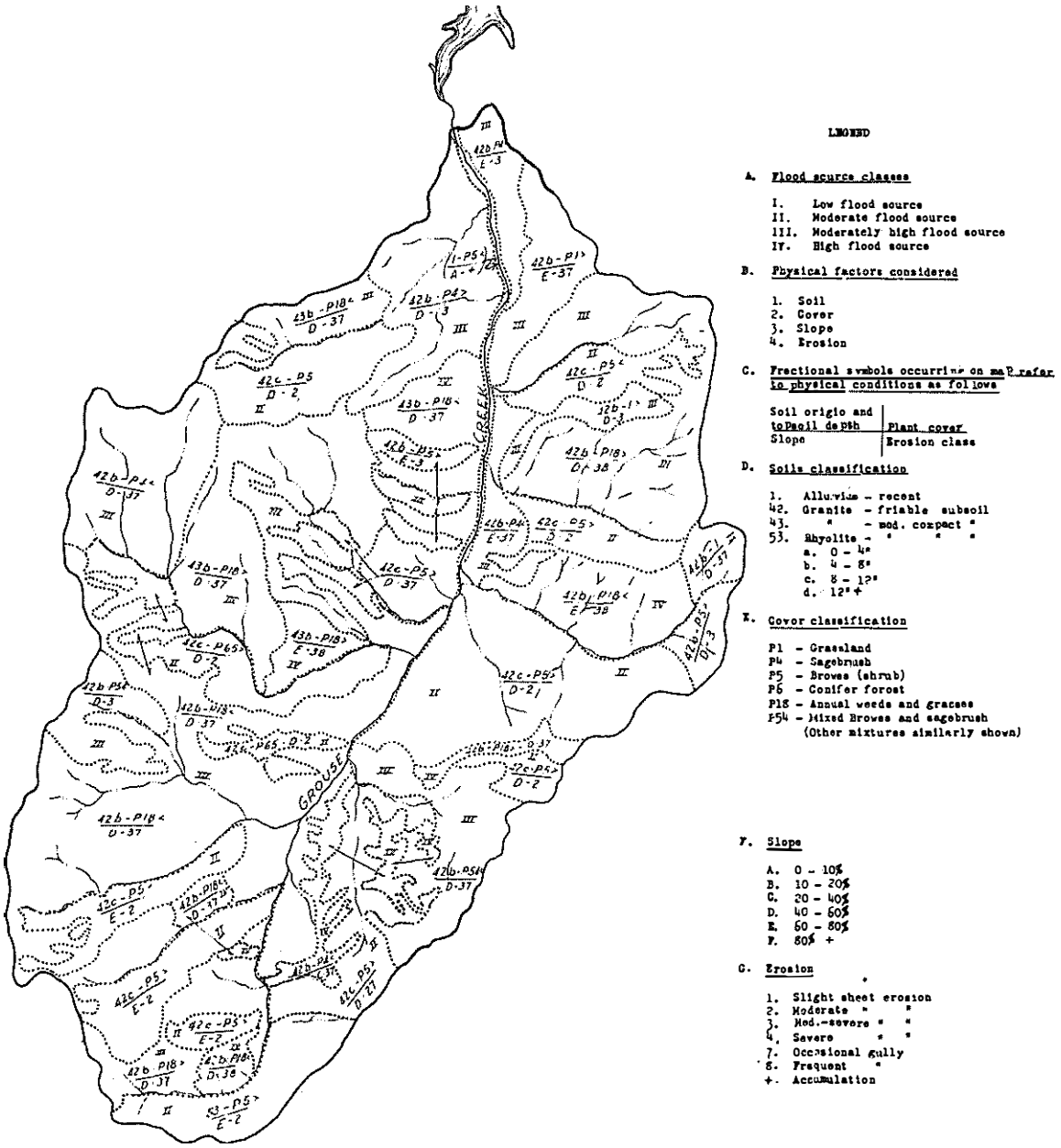


Figure 3.1 - Example of Range Hydrologic Condition Survey Map

Table 3.1.--Plant Cover Soils Survey

Sample Area No._____ Location _____ Plant-Soil Category _____

Examiner_____ Date_____ 19___ Total Acres _____

	Range Types						Forest Types			
	A = % acres			B = % acres			Litter			
	Condition (FS)	Density		Condition (FS)[3]	Density		Duff, Humus Depth-inches			Compaction
		High[1] Forest	Total[2]		High Forest	Total	L	H	A_1[4]	
Plant cover type										
Present density										
Future (no program)										
Future (w/program)										
Plant species										

[1] Canopy of high forest
[2] Incl. litter density and understory
[3] Flood Source: I = good, II = fair, III = poor, IV = very poor, V = geologic
[4] L = litter depth; H = duff on surface; A_1 = humus in soil

	Soil					Erosion[3]			Aspect	Slope	Bare Ground	
							Gully					
Subtype	Texture	Soil group	Eff. depth (inches)	Parent material	Sheet Type	Vol. (ac-ft)	Length (ft/ac)		N, S, E, W,	(%)	Dia. "	(%)
A [1]												
B [2]												

[1] Topsoil
[2] Subsoil
[3] Sheet erosion: slight = 1, mod. = 2, severe = 3
Gully erosion: shallow, occasional = 7; deep, frequent = 8

Land Treatment

	Comp. only	Reduct. Reseed	No. treat.	Reseed only	Broad reseed	Furrow resd.	Trench reseed	Gully Plugs	Grazing Mgt. % Red.	Excl.	
A % acres											
B % acres											

Management aids needed:

Utilization roads, miles _____	Rodent control	Acres	_____
Work " " _____	Water developments	No.	_____
Fences " _____	Head cuts	No.	_____
Driveways " _____	Road erosion	Miles	_____

Remarks:

Use subtype B, etc. for parts of area to be intensively treated, such as terraces.

The problem areas are further subdivided into plant cover types and within each of these, records are made of density, litter, and general vigor of the important species. The plant-cover types are classified as (1) herbaceous, (2) desert shrub, (3) browse, (4) pinyon-juniper, (5) aspen, (6) conifer, etc. Within each plant-cover type, estimates are made of the total plant and litter cover density or weight and separately for the high forest canopy, the brush cover, and the herbaceous cover. Densities can be estimated by 5-percent classes, or measured by various devices.

Concurrently with observation of the present physical condition of the watershed slopes, field estimates can also be made of the kind and amount of improvements needed to restore satisfactory conditions and of the probable effects of those improvements. The field estimates are based upon comparative observations on adjacent or nearby, potentially similar sites--a technique which, though not infallible, is considered to be sufficiently accurate for the purpose of the survey.

Several groups of improvement measures are considered for application on each site. For example, improved management involves estimates of the degree to which grazing use should be altered and of the amount of fencing and other developments which would be needed to facilitate the range-use adjustments. Revegetation needs are also estimated including consideration of seeding and tree or shrub planting. Estimates are made of the need for small mechanical structures such as contour furrows and trenches and gully plugs. Final estimates of management needs for each watershed unit are developed in part on the basis of the detailed field survey and in part through extensive inspection of other areas and consultation with administrative officers. Final estimates of the needs for structures and road-erosion control should be developed with the engineering division.

Estimates also are made of the probable effects of improved management and extensive land treatment on the runoff potential of the plant and soil mantle as one basis for evaluating the various improvement plans. Separate estimates can be made assuming that (1) no program would be installed, (2) management only would be applied, (3) intensive land treatment would supplement improved management, and (4) small mechanical structures would supplement intensive land treatment and improved management.

Analyses of the large volume of data obtained from the problem area surveys are made to develop qualitative relationships between the present and potential conditions of the numerous physical features considered and (1) the phenomena of infiltration and surface runoff, (2) soil moisture storage, snowmelt, and seepage flow, (3) sheet, gully, and channel erosion and sedimentation, and (4) forage and timber, and water production.

TABLE 3.2.--Hydrology Form Forest Range Watershed Survey (IBM) (Sheet 1)

Basin River Creek Twp. Rng. Sec. Cover Condition Soil Depth

Topographic					Soil							Cover										
Elevation			Exposure		Area		Soil profile				Soil Moisture		Parent material	Distribution					Condition			Land use		
														Type					Density			Land use		
(1000 ft.) M.S.L.	(500 ft.) above W.B. station	Land slope (10%)	Aspect (Azimuth)	Drainage area			Surface		Subsoil		Moisture (5%) before	Moisture (5%) after	Geology	Land form	Forest (10% area)	Brush (10% area)	Grass (10% area)	Rock (10% area)	Farms (10% area)	Forest density (5%)	Brush density (5%)	Grass density (5%)	Farms cover crops (5%)	Grazing (10%)	Burned (10%)	Cut-over (10%)
				10 sq. mi.	1 sq. mi.	Texture	Depth (feet)	Texture	Depth (feet)																
1	1	1 Slight	1 North	1	1	1 Sand	1 Shallow	1 Sand	1 Shallow		1 Dry	1 Dry	1 Granite	1 Valley	1	1	1	1	1	1 Poor	1 Poor	1 Poor	1 Poor	1 None	1	1
2									(2)								(2)	(2)							(2)	(2)
3				(3)	(3)										(3)	(3)										
4						(4)																(4)				
5	(5)		(5) East or West					(5) Loam			(5) Moist		(5) Sedimentary											(5) Mod.		
6							(6) Deep									(6)					Fair		Fair			
7		(7)												(7) Foothill												
8			(6)																	(8)						
9												(9) Wet														
10	10	10 Steep	10 South	10	10	10 Clay	10 V. Deep	10 Clay	10 V. Deep		10 Wet	10 Wet	10 Volcanic	10 Mtn.	10	10	10	10	10	10 Good	10 Good	10 Good	10 Good	10 Over	10	10

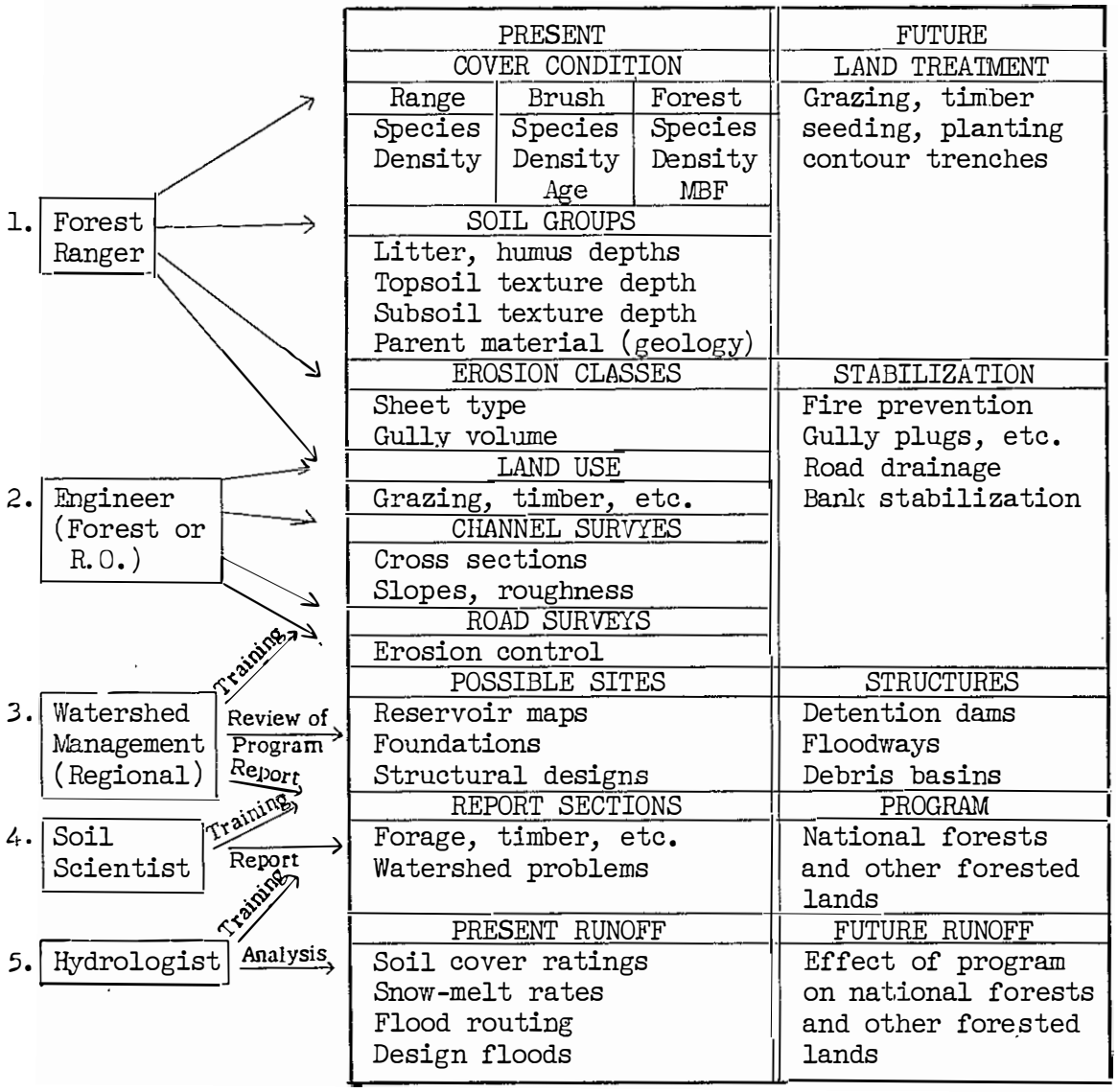
TABLE 3.2--Hydrology Form Forest Range Watershed Survey (IRM) (Sheet 2)

Weather Bureau Station Elevation_____.
Stream Gage (or estimate) Location____.

Climatic (weather bureau)									Runoff								Erosion						Damage				
Temperature maximum daily (10^{o} F-32)	Temperature cumulative (100^{o} F-32)	Wind maximum daily (5 m.p.h.)	Rain maximum daily (1/10 inch)	Antecedent fall rain (inches)	Winter precipitation (5 inches)	Snow (before) water content (10 inches)	Snow (after) (10 inches)		Flood depth (feet)	Cross-section (10 sq. ft.)	Channel slope (2%)	Roughness (n)	Velocity (ft./sec.)	Peak flow (100 c.f.s.)	(10 c.f.s.)	Unit discharge (10 c.f.s./sq. mi.)	Sheet	Gully	Channel	Turbidity	Sedimentation		Total ($10,000)	($1,000)		Private (10%)	Public (10%)	Federal (10%)
1	1	1	1	1	1	1	1		1	1	1 Slight	1	1 Low	1	1	1	1 Slight	1	1	1	1		1	1				
2			(2)				(2)									(2)												
3	(3)				(3)							(3) Debris flow, vegetated, rocky, sand, conc.																
4		(4)				(4)			(4)					(4)														
(5)				(5)							(5) Mod.		Med.				Mod.	"	"	"	"							
6										(6)																		
7																												
8													(8)		(8)													
9													High															
10	10	10	10	10	10	10	10		10	10	10 Steep	10	10	10	10	10	10 Severe	10 "	10 "	10 "	10 "		10	10				
Melt factors			Rainfall			Snow pack			High water computations					Discharge			Land			Waterborne			Flood damage downstream		Land ownerships		

The following flow chart (table 3.3) illustrates a desirable arrangement for conducting hydrologic surveys on national-forest lands. It also suggests the kinds of information which would be developed at different administrative and staff levels.

Table 3.3--Flow Chart for National Forest Hydrologic Surveys



3.2 - Sampling Procedure. The first job in conducting a watershed survey is one of determining what is to be sampled. As there are so many and great variations in the physical features of the watershed, it is by necessity that the area be stratified into more or less homogeneous units. These units need to be such that they can be tied down in terms of location and extent and will be of a composition that will enable them to be worked in with other basic data collected during the survey itself. It appears that a stratification based on vegetation and

soils would satisfy these demands as well as give the least variation in terms of infiltration, etc.

The next job is that of determining and delineating these infiltration strata or complexes. It would be beyond the realm of possibility to map all the vegetal types and soil types within the basin. Therefore, we must do some grouping to limit the number of types. For purposes of this discussion the vegetation has been placed into broad groups largely from the standpoint of watershed problems and infiltration characteristics. See following example.

Example Of Soil Cover Complexes

Range Cover Types

Grassland	Annual weeds Grass, sod Bunchgrass
Brush	North desert shrub South desert shrub
Woodland	Hardwoods Chaparral
Forest	Aspen Conifers

Soils	Texture	Depth	Parent Material
Heavy	Clay-silty clay Clay loam	Shallow 0-1'	Sedimentary (Limestone) (Sandstone) (Shale) (Alluvium)
Medium	Loam-silt loam Sandy loam	Medium 1-3'	Igneous (Extrusive-Volcanic) (Intrusive-Granite)
Light	Sand-gravelly	Deep 3'	Metamorphic (Schist) (Quartzite)

This brings us to the next step, the formulation of soil groups. What is the most logical breakdown for soils--great soil group? No, as such a grouping is meaningless in terms of infiltration and watersheds. Soil groups based on geology? This would be excellent because of published maps but the number of formations far exceeds the limits of sampling. How could this be simplified? It is entirely possible that the soils from each of the geologic formations could be placed into one of three broad textural classes: (1) light, (2) medium, and (3) heavy; and still use the geology maps for determinations of location and extent. Perhaps this

makes the breakdown too inclusive so another factor which influences infiltration should be considered, namely, soil depth. Arbitrarily the textural classes can be divided into two depth classes: (1) shallow or less than 1 foot in depth and (2) deep or greater than 1 foot in depth. Theoretically then there are 6 soil groups and more than 8 cover types or a total of 48+ strata to sample.

Obviously, adequate sampling of 48+ strata is still beyond the realm of practicability so a means of simplifying the job must be found. Inspection of the strata will give the answer. Several strata are likely to be nonexistent and can be eliminated from consideration. Next, a number of vegetation and soil types which are important from the standpoint of areal extent can be listed. Some of these and a few additional types can be considered important in view of watershed problems that are associated with them. Our next step would be to determine which of the soil classes listed has the most problems and support the greatest number of vegetal types and also which vegetal class has the most problems and occurs on the greatest number of soils. This would form the base for our experimental design from which data for all other strata might be interpolated. However, several strata should be tested because of importance of either problems or area so the next step would be to fill in these gaps, designating them by priority according to their relative importance. Our last step in this phase would be to determine how many of the strata had been sampled adequately at some previous date or place and of course eliminate these strata from the schedule. Actually, all the strata should be sampled but if time is limited we now know where the work should be concentrated and if all the first priority strata are sampled we have means for interpolating data for the remaining strata. Now the question arises of how much information has been provided for hydrologic evaluation (the differences of infiltration between present and future conditions for each strata) and how many tests have been made for each strata. The hydrologist might suggest 2 methods to choose from: (1) use density of the ground cover (vegetation and litter) as a variable within each complex and sample the full range of densities available (or at least 2 at the lower limits--the depleted plots--2 at the upper limits, and 2 in the middle). Density can be plotted against infiltration capacity and the resulting calculated regression or improvement curve can be tested for significance to show whether or not the sampling was adequate. (2) Stratify the vegetation-soil complexes into condition classes, preferably only 3. Sample each with no less than 3 plots for poor conditions, 2 for fair, and 1 for good. Then check the adequacy of sampling through standard deviation and a prearranged permissible error for variation in total ground-cover density.

There is one practical problem that must be given careful thought. How can these strata be sampled to give an answer nearest to reality? If plot selection could be randomized with as much variation in the strata as undoubtedly exists, the number of samples needed for a relatively accurate picture of infiltration would be astronomical. Also

the variation in watersheds is not purely on a random basis. The answer is to select plots using judgment as the basis. This predicates a knowledge of each stratum as well as confidence in surveyor's ability to select plots which represent the average of the stratum--without requiring statistical tests of sampling adequacy during surveys of the diversified conditions found on rangelands.

3.3 - Range Conditions

3.31 - Cover Types. A classification of broad vegetation types may consist of a number of plant communities where certain species occur in reasonably constant association. They occupy relatively continuous areas with boundaries established primarily by elevation, precipitation, and soil. Plant successions are similar throughout a given natural community. When vegetation is in equilibrium with the climate, site is a clue to future or climax condition. For watershed survey purposes it will not only be necessary to classify range types but also to study the forest, brush, and other communities not used for grazing. Since runoff characteristics need to be determined for present and future conditions, standards for judging forest and range hydrologic conditions need include only the major plant communities where runoff rates differ as determined by previous infiltration tests.

3.32 - Present Condition. Mountain rangelands must be managed to maintain those soils that are stable and to improve those that are eroding and contributing excessive runoff. A stable site is a prerequisite to a satisfactory condition of the cover; other products of the range are secondary. Although range forage must be judged along the lines of natural plant succession, satisfactory runoff and erosion conditions can be attained by vegetation of a lower stage but with adequate density and litter production.

It is generally recognized that site conditions limit the development of plant communities. The major environmental factors include climate, parent material, topography, soils, etc. The amount and availability of soil moisture is perhaps the major influence on plant distribution, density, and form. Plant succession is in the direction toward improved mositure conditions by helping develop deeper, mature soils with humus until final equilibrium with the climate is reached.

Range condition is judged excellent if near the climax stage of plant succession, since that is the ultimate to be expected at the site and climate, yet lands used for grazing can hardly be expected to return to a truly pristine condition. Good condition means satisfactory for forage and soil stability in range survey work; fair and poor conditions are below this potential productivity of the site. However, this classification is only part of the hydrologic condition calculation.

It is generally accepted that the factors of density, composition, and vigor should be considered in judging range forage conditions, while

total ground cover including litter and humus indicates hydrologic or runoff conditions and erosion reflects soil stability. Another characteristic is dispersion or the size and pattern of bare soil spaces; this affects both surface runoff and soil erosion. Table 3.4 lists those range-condition indicators which are considered to have hydrologic significance.

Table 3.4 --Range Condition Indicators[1]

		Hydrologic Significance
1. Cover and litter	Good - well dispersed, accumulation of litter Poor - scanty accumulation of litter	Yes
2. Bare soil	Good - absent or small well dispersed spots Poor - large areas present	Yes
3. Soil movement	Good - slow, loss less than development Poor - observed loss	Yes
4. Soil remnants	Good - no islands or relics of former levels Poor - relics of former levels present Fair - invasion by vegetation, roots exposed	Yes
5. Erosion pavement	Good - no concentration of gravel or rock on surface Poor - concentration on surface Fair - invaded by plants	Yes
6. Gullies	Good - no recent channels for accelerated overland flow, rapid drainage of snow-melt Poor - active recent channels Fair - self perpetuating	Yes
7. Blowouts	Good - no depressions in surface by wind erosion Poor - depressions in surface present Fair - covered by gravel pavement	No
8. Wind deposits	Good - no fine material leeward of patches or vegetation Poor - recent fine material present	No

[1] Ellison, L. E. and Croft, A. R., "Condition and Trend of Range Watersheds," Research Paper No. 6, Intermountain Forest and Range Experiment Station, 1944

Table 3.4--Range Condition Indicators--Continued

		Hydrologic Significance
		Yes
9. Alluvial deposits	Good - no dislodged water-transported deposits on fans or upstream slopes Poor - recent deposits present Fair - perennial or woody vegetation established	
10. Species	Good - high forage value (extent of depletion of pristine stand) Poor - dominant undesirable species Fair - mixture of desirable and undesirable species	No
11. Age classes	Good - grouped age classes (old and new) Poor - no new plants Fair - dying out of undesirable species	No
12. Annual weeds	Good - no periodically disturbed soil Poor - abundant disturbed soil Fair - protection of exposed soil	Yes
13. Invasion	Good - on bare places Fair - by desirable species, by seed	Yes
14. Gully vegetation	Good - present Poor - bottom only Fair - established on side slopes, renewed cutting in bed	Yes
15. Patchy vegetation	Good - no departure from characteristic mingling of species Poor - abrupt and repeated departure	No
16. Accessibility	Good - uniform distribution of palatable species Poor - palatable species confined to inaccessible spots Fair - young desirable species	No
17. Relics	Poor - desirable species Fair - young plants	No
18. Hedged stands	Poor - present Fair - normal growth above hedged	No
19. Utilization	Poor - current heavy Fair - threat of future conditions, lack of reproduction	Yes

3.33 - Future Condition. A change has taken place in the plant cover of many watersheds. To determine the amount and kind of such changes, studies may be needed of areas which are thought to be at or near their virgin condition. Cemeteries, protected areas in fields or range pastures, fenced experimental plots or demonstration areas, range isolated because of natural barriers, and areas which were known to have been moderately stocked for a long period can be studied and compared with adjacent similar areas where grazing has not been controlled or the area protected.

These studies may show that there had been a change both in density, in composition, or in both. Sometimes there occurs only a change in composition as the density has been maintained by a substitution of other plants. Usually there is a decrease in density as well as a change in composition. The usual change is from perennial grasses and weeds to annuals or to perennial plants that were less palatable to the animals and which also gave the watershed less protection against runoff and erosion.

The study may also show that flood source is closely associated with cover type as well as density and composition. The more serious flood-source classes are usually found to occupy a relatively larger percent of the total area of the herbaceous or pinyon-juniper types than on the other types. Aspen and conifer types usually contain relatively low percentages of severe flood sources while the sage and browse types are intermediate in flood-source conditions.

When the cover types are broken into density groups, there is a close relationship between the percentage of high flood source and low ground cover density. The high flood source is directly related to low density of plant cover. Weed types are usually associated with high flood source, and other things being equal, the higher the percentage of weeds and annual grass type the greater the flood source.

3.4 - Hydrologic Condition. Present and potential runoff conditions (hydrologic conditions) result from many properties of the site--humus, soil, geology, climate, slope, erosion, and use factors in addition to the plant density. If the soil is shallow or impervious, for example, the rating should give high runoff regardless of a complete ground cover. Soils that are deep and sandy should have a rating that would produce low runoff, even with sparse cover. A soil-cover complex rated adequate for a small storm might not have the same rating in regions subject to large or very intense storms. Steep and erodible slopes require more cover for the same degree of protection.

However, the observation of ground cover density remains of primary importance since this is the factor most subject to change through management. It is the intent to utilize range surveys now being made according to current handbook instructions with supplementary observations at the site to bring out clues to the hydrologic condition of the area. Especially helpful are those describing the soil profile.

Table 3.5.--Transect Cluster Summary and Current Range Condition Rating[1]

Forest_____ District_____ Allotment_____ Date_____

Cluster or Sample No._____ No. of Transects_____ Aerial Photo No._____

Major Range Type_____ Location of Area Covered_____

Scorecard Used_____ Examiner_____

DENSITY AND GROUND COVER INDEX

Item	Transect No. 1	2	3	Tot	Ave.
Bare Soil					
Erosion Pavement					
Rock					
Moss					
Litter					
Plant Density Index					
TOTAL	100	100	100	100	100
Forage Density Index					
Ground Cover Index					

VIGOR SUMMARY

Species	Transect No. 1	2	3	Tot.	Ave.

COMPOSITION

Species Symbol*	COMP. TALLY T 1	T 2	T 3	Total Comp. Tally	Ave. % Total Plant Comp.
Desirable					
Other					
Total					
Intermediate					
Other					
Total					
Least Desirable					
Other					
Total					

*List Important Species - Group others.

Percent of Protected_____

Remarks:

CLASSIFICATION OF CONDITION RATING

VEGETATION

Forage Density Index_____

Composition _____

Vigor _____

Total _____

Condition Class _____

SOIL STABILITY

Erosion Hazard _____

Current Erosion _____

Total _____

Condition Class_____

[1] U.S.F.S. - Region 2 - 1957

All Items Below Are To Be Checked if Applicable
(Observation Basis)

Soil Indicators

Bare Soil: 0 - 20% _____ 21 - 50% _____ Over 50% _____
Bare Areas: Small, well dispersed _____ Patchy _____ Large, extensive _____
Litter: Accumulating _____ Replaced Annually _____ Not Replaced _____
" Quality: Good (grass) _____ Fair (mixed) _____ Poor (trash) _____
" Quantity: Heavy _____ Moderate _____ Light _____
Observed Soil Movement: None _____ Slight _____ Moderate _____ Severe _____
Pedestals (plant or rock): None _____ Few _____ Numerous _____
Soil Remnants: Vegetated on sides _____ Sloping sides _____ Steep sided _____
Erosion Pavement: None _____ Forming _____ Pronounced _____
Rill Marks: None _____ Few (after heavy storm) _____ Common _____
Gullies: None _____ Occasional _____ Frequent _____
Shallow _____ Deep _____ Steep Sided _____
Sides Stabilized _____ Bottoms stabilized _____ Bottoms cutting _____
Soil Deposits (wind or water): None _____ Occasional _____ Frequent _____
Soil Surface: Loose and Friable _____ Slight crusting _____ Compacted _____
Trampling Displacement (or trailing): None _____ Slight _____ Pronounced _____

Vegetation Indicators

Vigor (Desirable and Intermediate spp.): Good _____ Fair _____ Poor _____
Composition Changes
Desirable spp.: Increasing _____ Maintaining Stand _____ Decreasing _____
Intermediate spp.: Increasing _____ Maintaining Stand _____ Decreasing _____
Undesirable spp.: Present (normal) _____ Abundant (50% +) _____ Increasing _____
Annuals: Few _____ Abundant _____ Dominant _____ Species _____
Age Classes: (Indicate age class or classes present. Mark X if abundant.)
Desirable spp. Seedlings _____ Young _____ Mature _____ Old _____ All _____
Intermediate spp. Seedlings _____ Young _____ Mature _____ Old _____ All _____
Undesirable spp. Seedlings _____ Young _____ Mature _____ Old _____ All _____
Dead Centers of Bunchgrass: None _____ Few _____ Conspicuous _____
Invasion of Bare Areas By: Desirable spp. _____ Intermediate spp. _____ Undes. spp. _____
Browse Condition (hedging): None _____ Moderate _____ Severely _____ Dying _____
Current Utilization (at end season): Light _____ Moderate _____ Heavy _____
Are palatable plants well distributed? _____ In protected areas only? _____
Are "Relics" present? _____ If so, what species? _____

Notes on the General Type or Use Area Sampled By this Cluster:

Site productivity (low, average, high) _____
Soil (parent material and top soil texture) _____
Slope (percent) _____ Direction _____
Problems: (poisoneous or noxious plants, rodents, big game, etc.

_____
_____
_____
_____

Range Improvements needed or management recommendations:

_____
_____
_____
_____

Usability Adjustments: Slope _____ % Timber or Brush _____ %
Lack of Water _____ % Other _____ % Total Adjustment _____ %

Table 3.6.--Summary of Present and Future Condition[1]

_____ Watershed Write-up Number_____

Examiners_____ Date_____

Soil-Plant Cover Group_____ Area (Acres)_____

Soil description_____

Plant cover description_____
(use standard range symbols)

Location_____
(section, drainage, etc.)

	PRESENT CONDITION CLASSIFICATION					
	Condition	Rating	Condition	Rating	Condition	Rating
Type breakdown (%)						
Proper use factor						
Soils						
Composition (density)						
Bare rock (%)						
Perennials (grass + shr.)						
Weeds + annuals						
Total ground cover (%)						
Plant vigor (G, F, P)						
Slope (%)						
Erosion - Sheet (L,M,S)						
- Gully						
TOTAL OF NUMERICAL RATINGS						
CONDITION CLASSIFICATION						
	FUTURE CONDITION WITH PROGRAM					
Composition - Perennials % density						
- Annuals%						
Total ground cover						
Vigor						
Erosion - Sheet						
- Gully						
Proper use factor						
CONDITION CLASS						

(Put remarks on back)

[1] U.S.F.S. -Intermountain Station

3.41 - Ground Cover. Included in the total ground cover are the living plants and their litter. The kind and amount of vegetation determines the quality and quantity of litter. Litter is an important part of the ground protection because it retards runoff, improves the organic content of the soil, and thus increases the infiltration rate and storage capacity. Perennial grasses furnish more effective litter than annuals or weeds. As density of vegetative cover decreases, the production of litter declines and more soil is exposed to accelerated runoff and erosion. Other factors which may be considered are moss, rock, and erosion pavement.

Ground cover density may be measured by several methods which give adequate estimates for hydrologic ratings. However, the procedure using temporary paced transects has been described as a standard in range survey handbooks (reference tables 3.5 and 3.6).

The number of paced transects will vary with the density of cover within each subarea. An area in poor condition should have 3 transects, fair condition 2, and good condition 1 transect. The examiner should take 100 paces, considered a transect, preferably in a straight line through a representative part of the type. At each of the 100 points he is to record hits on vegetation, litter, bare soil, rock, etc. In brush types the high canopy will be recorded separately. The size of openings or dispersion of the plants will be observed. Composition of desirable species for range management uses can also be recorded if desired. Hydrology is mainly concerned with runoff and erosion ratings; therefore only the total ground-cover densities by species including litter need be reported on the hydrologic summaries for a condition rating.

3.42 - Erosion. Land surfaces may be subject to raindrop splash in addition to sheet gully, and wind erosion. Erosion is influenced by the type of soil, amount of vegetative cover, topography, and climate. Normal geologic erosion cannot be detected on the better sites since it must be slower than the formation of soil. Geologic erosion can be rapid and spectacular on some exposed formations. The initial stage of accelerated erosion is slight and difficult to detect but is evidenced by signs left from runoff. These are litter lodged against plants, fine silt deposits on leaves, and small patches of sediment deposited where runoff was retarded. It may be that considerable time has elapsed since a storm of sufficient intensity has occurred so that signs will have been obscured.

With moderate erosion the signs are more conspicuous. Indicators are rill marks or shoestring gullies, erosion pavement, pedestaled plants, sparse litter, silt deposits, runoff visibly muddy, etc. Evidence of severe erosion are pedestaled plants with exposed roots, gullies, exposed subsoil, extensive erosion pavement, outwash fans, etc.

Sheet erosion is best recorded in terms of inches of topsoil lost from the area in the period of years observed. Gully cross sections are measured and averaged for the length visible on subareas to give the volume of material eroded.

While the purpose of hydrologic surveys of rangelands should not be confused with soil surveys, the characteristics of soils which determine infiltration rates should be observed on each subarea or sampling unit. Whenever possible, standard soil survey procedure, adopted to mountainous conditions, should be utilized in this appraisal. Soils information which should be assembled as part of the hydrologic survey include the following:

Texture	-	surface and subsoil
Depth	-	surface and subsoil
Permeability	-	surface and subsoil
Organic content		
Humus type and depth		
Parent material		
Drainage		

When laboratory facilities are available, soil samples may be tested for ratings concerning percolation, water storage, etc., and the results utilized in classifying site characteristics in the manner illustrated by table 3. 7.

On those watersheds where soil surveys have been made by the Forest Service as described in FSM, FSH 2512, the information so obtained provides an excellent source of information for hydrologic classification of the areas surveyed.

3. 5 - Examples. The following hypothetical rating tables and instructions are intended to illustrate the effect of soil cover and land use factors upon hydrologic conditions or runoff ratings. The numbers can be considered as simply the percent of large rains which runs off as either overland flow or subsurface seepage. Refer to FSH 3502 for more detailed description of the use of runoff curve numbers.

Example of Rating Table for Hydrologic Condition

Brushland for Large General Storms

Soil	Topsoil	Subsoil	Depth	Geology	Total
Group (A) Light	10	15	10	25	Deep = 60
Group (B) Med	15	15	20	30	Medium = 80
Group (C) Heavy	20	20	20	30	Shallow = 90
Group (D) Extreme	25	20	20	30	Extreme = 95

Cover - Forest and Brush Canopy

Burns	0-10%	11-30%	31-60%	61-100%
1 yr.	20+40[1]	([1])	([1])	([1])
3 yr.	5+10	0+5	0-5	---
5 yr.	0	0-5	-5-10	-10-15
10 yr.	---	5-10	-10-20	-20-25
30 yr.	---			-25-35

Storm Rainfall	Duration	
Depth		
2-5"+20	1 day	0
5-10"+5	2 days	-5-10[1]
10-20" 0	5 days	-20-40

Antecedent Rainfall			
Dry	-10	-15	-20
Aver.	95	80	60
Wet	+5	+15	+20

[1] Subtract greatest effect on sandy soils(A).

EXAMPLE OF RATING TABLE FOR HYDROLOGIC CONDITION

RANGELAND FOR INTENSE LOCAL STORMS (1-2")

Soil Texture	Topsoil	Subsoil	Depth	Total	
(A) Light	30	10	20 deep	60	(highest infiltration)
(B) Med.	40	15	20 medium	60	(above average infiltration)
(C) Heavy	45	20	25 shallow	90	(below average infiltration)
(D) Extreme	50	20	25 extreme	95	(extremely impervious)

Ground Cover			Forest or Brush Canopy					
	Herbs	Density %	0-10%	11-30%	31-60%	61-90%	91-100%	Composition
Understory	(Grass and Litter)	0-10	0-1[1]	2-5[1]	5-10[1]	10-15[1]	15-20[1]	Bunchgrass -1
		11-30	2-5	5-10	10-20	20-30		Sodgrass +2
		31-60	4-10	10-15	20+30	30-40		Annual weeds +5
		61-90	7-15	15-20	30-40			Dispersion
		91-100	10-20	20-30				Small +1
								Med. 2
								Large 3

[1] From the soil rating, subtract the cover rating using greatest reduction for lightest soils (A).

Land Use	Grazing (Compaction)	Burns	Erosion	Sheet	Gully
			Slight	+1	+5 Shallow, few
			Mod.	2	7 Moderate
	Light +1	Recent (0-1 yr) +50	Severe	3	10 Deep, freq.
	Med. 2	Aver. (3-5 yr) +10			
	Heavy 3	Old (10-20 yr) +1			

Storm Rainfall

Intensity	Duration 15 min.	30 min.
Slight (0.1"/hr.	-100	-70 -50
(1-3"/hr.	-10	-0 +0
(3-6")	+10	+15 +20
(6-10")	+20	+30 +50

Antecedent Moisture			
Average	90	80	60
Wet	+5	+10	+15

Instructions for use of tables for determining hydrologic ratings:

1. Soil Ratings

a. Give the soil profile a rating for relative infiltration rate of topsoil in regions where small storms (1-2") cause overland flow without saturating the entire mantle.

b. Rate the subsoil including effective depth for storage capacity and percolation in regions where large storms (10-30") saturate the entire profile and produce some direct subsurface runoff.

c. Where floods are mainly direct subsurface flow, use alternate rating for underlying geology; and discount soil factors unless overland floods are involved (recent burns, etc.)

2. Cover Ratings

a. For rangeland, deduct the rating based on total ground cover density, from the previous rating estimated for bare soil. Use the greatest deduction for the lighter soils with better structure; use the least effect on heavy or shallow soils. Alternate observations of composition, vigor, forage, dispersion, etc. may be used.

b. For brush cover (chaparral) add a rating for recent burns over a period of years until control of overland flow is established.

c. For forest and woodland, deduct a rating based on depth of humus.

3. Erosion Ratings. Add a rating for effect of past erosion on runoff production. Erosion pavement may require a small correction factor.

The alternate observation would be the physical factors affecting erodibility such as geology, slope, or a correction for size of bare soil openings.

4. Land Use. For rangelands add a rating for grazing use to express compaction, etc.

Range use might also be expressed in terms of forage production (lbs./acre) as an alternate observation.

5. Rainfall Ratings. A rating must be added for the storm types and antecedent moisture conditions that the watershed must withstand. Add a rating for intensity of storm where the runoff is overland flow. For general storms add a rating for depth of rainfall and subtract a

Table 3.7--Hydrologic Site Characteristics for Computing Runoff

	Surface[1]		Topsoil[2]		Subsoil[3]		Parent Material[4]	
	Overland Flow (in./hr.)	Storage (inches)	Infiltration (in./hr.)	Storage (inches)	Percolation (in./hr.)	Storage (inches)	Permeability (in./hr.)	Storage (inches)
Highest	5.0+	3.0+	5.0+	5.0+	2.0+	5.0+	0.5+	20.+
High	.2.0-5.0	1.0-3.0	2.0-5.0	2.0-5.0	0.5-1.5	2.0-5.0	0.2-0.5	10.-20.
Medium	1.0-2.0	0.5-1.0	1.0-2.0	1.0-2.0	0.3-0.5	1.0-2.0	0.1-0.2	5-10
Low	0.5-1.0	0.1-0.5	0.5-1.0	0.5-1.0	0.1-0.3	0.1-0.3	.05-.10	1-5
Lowest	0.1-0.5	0.0-0.1	0.1-0.5	0.0-0.5	.01-.10	0.0-0.1	.01-.05	0-1

[1] Litter, humus, or depressions. Detention storage related to overland flow depth.

[2] Detention storage separated from retention. Estimate antecedent moisture to retention.

[3] Transmission time = detention storage ÷ percolation rate.

[4] Storage vs discharge relation derived from stream gages.

rating for duration of rainfall if not broken down on less than daily basis.

Adjust for frequency of the rainfall event for rare storms from which watershed cannot be expected to be protected.

Antecedent moisture saturating the mantle before greatest annual floods can be integrated by adding a rating. Add only 5 points to poor conditions at high runoff ratings up to 20 points for good conditions at low runoff ratings.

6. Total Rating. Add up all the individual ratings algebraically (steps 1-5) and adjust the total to the actual runoff from storms if the area is gaged. In ungaged areas, the total rating number can be checked with the runoff curve numbers in figure 3.2.

The total runoff rating now indicates whether the watershed is in a good or poor hydrologic condition based on all factors measured to have an influence on direct runoff.

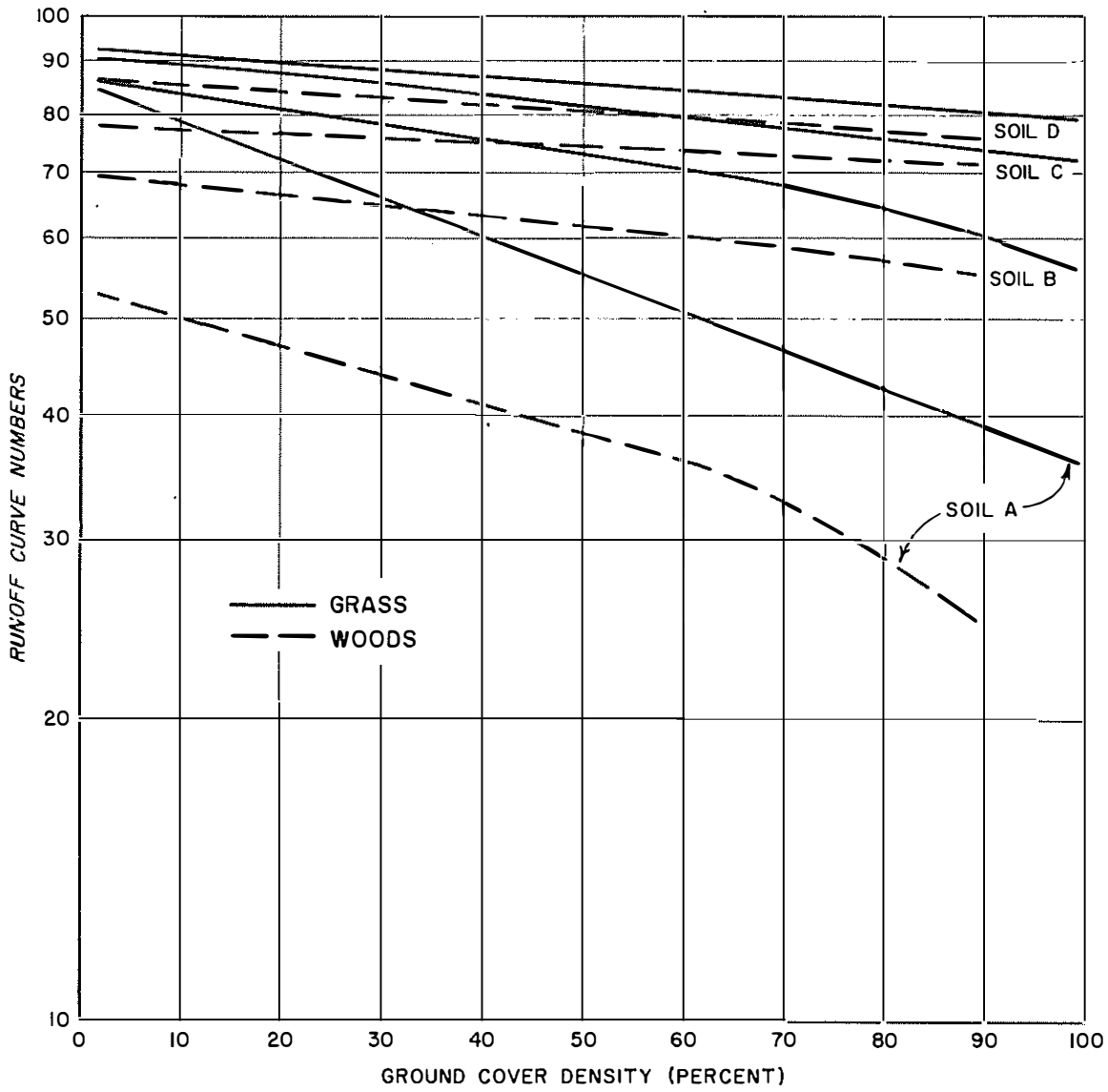
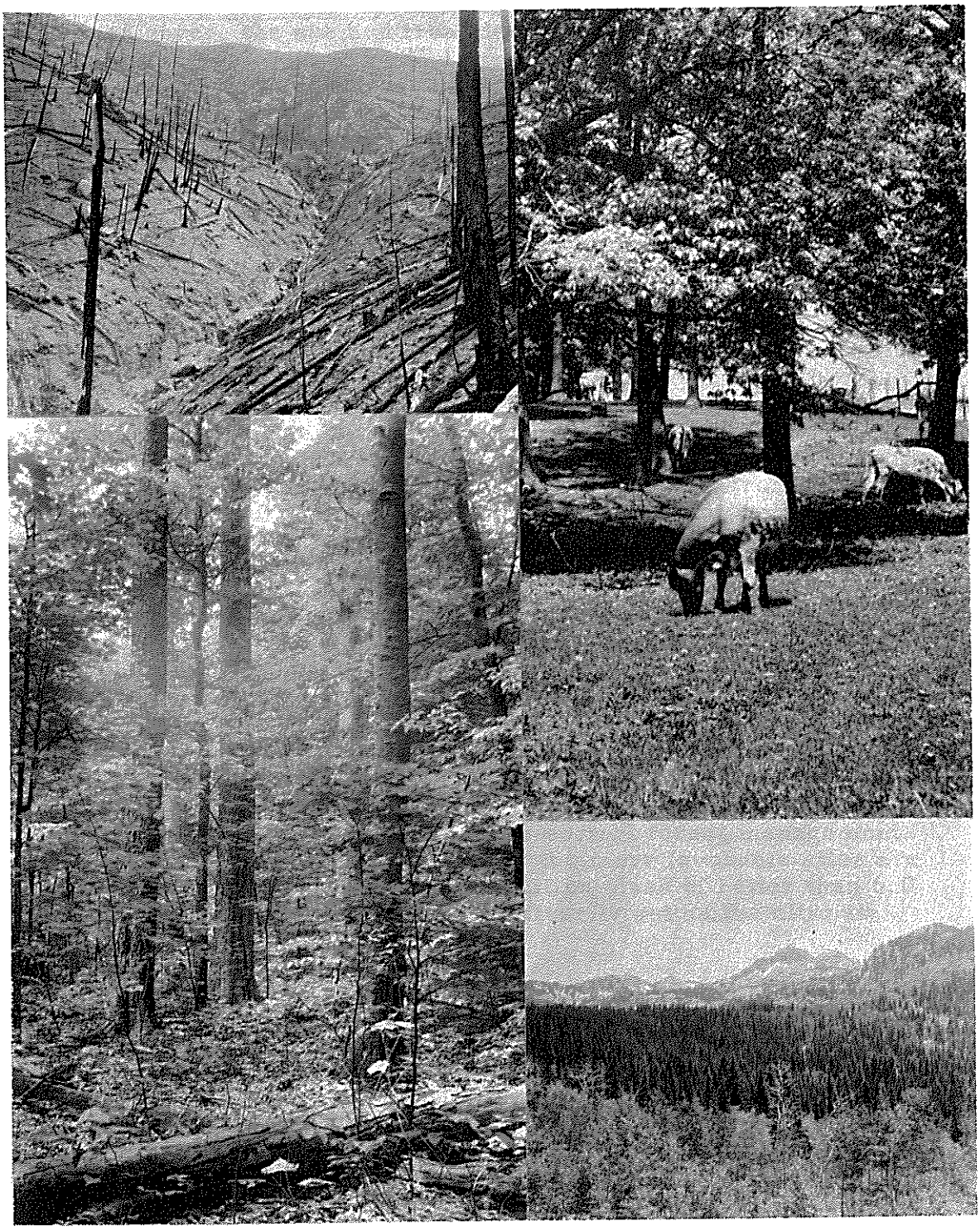


Figure 3.2 - Hydrologic Condition of Rangeland
from Soil Conservation Service

FOREST HYDROLOGIC CONDITION SURVEYS

CHAP. 4



CHAPTER 4

4 - FOREST HYDROLOGIC CONDITION SURVEYS

4.1 - Hydrologic Condition. A complex relationship exists between woodland cover, the use and treatment of this cover, the soil, and runoff. Species, age of stand, stand density, burning, grazing, cutting, and logging affect the physical characteristics of the surface soil horizons which in turn affect the kind and amount of runoff. It is obvious that with several cover types, numerous age classes, and several kinds of use and treatment, there could be as many as several hundred different cover complexes in the woodland areas occurring in a single watershed. Since the use of such a large number of cover complexes, each of which has a characteristic runoff relationship for each soil group, would greatly complicate the evaluation procedure, a device called "hydrologic condition," is used to integrate the complexes into a relatively few evaluation factors. Hydrologic condition is defined as that condition of a watershed area which reflects its ability to influence runoff.

Although qualitative terms such as "poor" or "good" are sufficient for describing forest hydrologic conditions generally, a quantitative basis is more desirable for deriving runoff curve numbers from forested areas. For this purpose, the following six numerical hydrologic condition classes, subject to subdivision into one-tenth classes have been developed for forested areas:

Class 1. - 1.0 through 1.9; very poor hydrologic condition.
Class 2. - 2.0 through 2.9; poor hydrologic condition.
Class 3. - 3.0 through 3.9; average or fair hydrologic condition.
Class 4. - 4.0 through 4.9; good hydrologic condition.
Class 5. - 5.0 through 5.9; very good hydrologic condition.
Class 6. - 6.0 and above; excellent hydrologic condition.

Some sites are so poor that classes 5 and 6 would not be attained within the economic rotation age under normal forest management practices. On the other hand, some of the more favorable sites are capable of producing a hydrologic condition class of better than 6.0, but for practical purposes, 6.0 is arbitrarily set as the ultimate attainable.

Criteria for Determining Hydrologic Condition. Although a number of criteria may be used for determining the effect of land use upon hydrologic condition, the most simple procedure giving consistent results involves only the depth of litter, humus depth, and humus type. These are integrated in an alignment chart for determining present hydrologic condition as shown in figure 4.1.

Litter Depth. Litter consists of the "L" layer of the forest floor, also described as the A_{oo} horizon. It consists of undecomposed leaves

and/or needles, together with twigs, bark, etc., figure 4.2, and varies in depth with season, being thickest in the fall and thinnest in late summer.

In regions of light rainfall the detention of rainfall in litter is an important factor in controlling runoff. However, in regions subject to heavy and prolonged rainfall, the most important hydrologic functions of litter are to protect the soil from erosion, protect the humus from oxidation, and to provide food for humus-forming animal and plant soil life. Litter breaks the force of impact of raindrops as they strike the ground. Where bare soil or mull type of humus is present, the cushioning effect of the litter prevents the raindrops from splashing the soil and sealing the soil pores. It serves as an excellent insulating material which prevents the rapid oxidation and breakdown of humus. As a food source for humus-forming soil life, litter affects the type of humus and the rate at which humus is formed, and the amount of humus accumulated. Usually one-quarter (1/4) inch in the late summer before leaf fall or one-half (1/2) inch following leaf fall is a sufficient depth for litter to function properly with respect to hydrologic functions.

Humus Depth. Humus is the organic layer laying immediately beneath the litter layer from which it is derived. It may consist of (1) mulls consisting of the A_1 horizon of an intimate mixture of organic matter and mineral soil or (2) mors consisting of the "H" layer or A_{o2} horizon which is practically pure organic matter unrecognizable as to origin lying on the mineral soil.

On forested areas the depth of humus increases with age of stand until an equilibrium is reached between the processes that build up the humus and those that break it down. Although as much as 12 inches or even more may be produced under very favorable conditions, a depth of 5 to 6 inches is considered to be the maximum attainable under average conditions. Since as much as one-half inch of water can be held in detention storage by each inch of humus, depth of humus is an important criterion of hydrologic condition.

Humus Type. Humus is very sensitive to land-use and treatment. Under good use and treatment, it is porous and has high infiltration and detention storage capacities, but poor management practices as burning, overcutting, and overgrazing converts porous humus to a compact one which impedes the absorption of water. Since compaction is the principal factor affecting infiltration and because the degree of compaction is closely related to humus type, humus type is used as the criterion for compaction.

Three degrees of compaction, as expressed by compaction factors, are recognized in determining hydrologic condition:

1. Compact: Compaction Factor 1; characterized by firm mull or felty mor.

Firm Mull: A_1 horizon, an intimate mixture of mineral soil gradual transition to underlying horizon, and with generally less than 5 percent organic matter by weight; massive and firm.

Felty Mor: H layer with practically no mixing of organic matter with mineral soil, abrupt transition from surface organic matter to underlying horizon, feels and looks felty due to the presence of fungal hyphae and/or plant residues but not living roots.

2. Moderately Compact: Compaction Factor 2; characterized by transitions between (1) firm mull and other mulls and mors other than felty mors, (2) felty mors and other mors, and mulls other than firm mull.

3. Loose, not compact, friable; Compaction Factor 3; characterized by mulls other than firm mulls and mors other than felty mor.

Frost and Humus Type. Frost occurrence and the type of frost are related to humus type. In compact humus such as firm mull or felty mor and sometimes in the transitions to the better humus types, frost usually occurs in the concrete form, occasionally with ice lenses. This type of frost inhibits infiltration. In the porous, and usually in the transition humus types on the loose side, the frost occurs in the granular or stalactite forms which do not adversely affect infiltration. In fact, stalactite frost which usually occurs in the better mulls actually improves infiltration. Because of this relationship of frost to humus type, no special adjustment for frost is necessary.

Measurement of Forest Hydrologic Condition Criteria. Litter depth, humus type, and humus depth are measured from shallow soil wells dug at three sampling points within the sample plots. One sampling point is located at the plot center, the second at five paces north, and the third at five paces south of plot center.

At each sampling point, litter depth is to be measured to the nearest one-quarter (1/4) inch, humus type identified, and humus depth measured to the nearest one-tenth (1/10) inch. Due to the variation in humus depth, an average of three measurements will be used as the depth at each sampling point.

Determination of Present Hydrologic Condition. Present forest hydrologic condition is determined as follows:

Using figure 4.1, place straight edge on scale H at point indicating depth of humus layer and on scale C indicating degree of compactness of humus layer, read present hydrologic condition class on scale HC to one-tenth (0.1) class as, for example, 2.3. The forest floor should be covered by at least 1/4 inch of litter in the late summer and 1/2 inch at other seasons as protection to the humus layer. If this minimum amount of humus is not present, reduce the hydrologic condition by

five-tenths (0.5) of a condition class, but not less than class 1.0. For example, if the adjusted hydrologic condition fell below 1.0, as 0.9, or 0.5, the hydrologic condition class would be 1.0.

Illustrations of the determination of the present forest hydrologic condition are given below.

1. Compaction 1, sufficient litter.
   Humus type: Firm mull.
   Humus depth: 1.6 inches.
   Litter depth: 3/4 inch. Summer season before leaf fall.

Present hydrologic condition class is 1.9. Because litter depth is sufficient, no adjustment in hydrologic condition class is necessary.

2. Compaction 1, insufficient litter.
   Humus type: Firm mull.
   Humus depth: .6 inch.
   Litter: 1/8 inch. Summer season before leaf fall. Present

hydrologic condition class is 1.3. Because litter depth is insufficient, reduce hydrologic condition by 0.5 class to 0.8. Inasmuch as the lowest forest hydrologic condition class is 1.0, the adjusted hydrologic condition would be 1.0 instead of 0.8.

3. Compaction 2, sufficient litter.
   Humus type: Transition from felty mor to coarse mull.
   Humus depth: 2.5 inches.
   Litter depth: 1/2 inch. Spring, before leaf fall. Present

hydrologic condition class is 2.9. Because litter depth is sufficient, no adjustment in hydrologic condition is necessary.

4. Compaction 2, insufficient litter.
   Humus type: Transition from firm mull to coarse mull.
   Humus depth: 2.0 inches.
   Litter depth: 1/4 inch. Fall season following leaf fall. Pres-

ent hydrologic condition class is 2.7. Because litter depth is insufficient, the hydrologic condition class is reduced by 0.5 class from 2.7 to 2.2.

5. Compaction 3, sufficient litter.
   Humus type: Greasy mor (other mor).
   Humus depth: 6.2 inches.
   Litter depth: 2 inches. Winter following leaf fall. Present

hydrologic condition class is 5.5. Litter depth is sufficient, so no adjustment in hydrologic condition class is necessary.

4.2 - Future Forest Conditions

1. Hydrologic Condition Improvement Potential. The depth of litter, humus type, and depth of humus are readily measured for determining present hydrologic condition, but they must be estimated

for determining hydrologic condition at any time in the future. In making these estimates, due consideration is given to the rate of change from poor-to-good humus types and the rate of humus accumulation as affected by (1) the physiographic factors of the site and (2) planned use and treatment.

The physiographic factors affecting the criteria used for determining forest hydrologic condition are aspect, texture of the mineral soil horizon lying immediately below the humus layer of the surface soil in the absence of a humus layer, depth of soil mantle, percent of slope, and position on slope, figure 4.3. The integrated effects of these physiographic factors is reflected in the "Hydrologic Condition Improvement Potential" which is the relative capability of the site to improve hydrologic condition. Hydrologic condition improvement potential is separated into three classes:

H = High hydrologic condition improvement potential, represented by physiographic conditions producing the most rapid rate of improvement in forest hydrologic condition.

M = Medium hydrologic condition improvement potential, represented by physiographic conditions producing an average rate of improvement in forest hydrologic condition.

L = Low hydrologic condition improvement potential, represented by physiographic conditions producing the slowest rate of improvement in hydrologic condition.

The integration of these physiographic factors with hydrologic condition improvement potential is shown in table 4.1.

The physiographic factors used in table 4.1 are defined as follows:

Aspect--To be taken to the nearest octant with a compass from the plot center looking down slope on a line at right angles to the contours.

Soil Class--Soil texture of the mineral soil horizon immediately below the A or H humus layers at the center of the plot.

Soil Depth--Taken at the center of the plot with a soil punch or soil auger. Place rock outcrops or soils less than 13 inches in depth in the 13- to 24-inch class.

Slope Position--Taken at center of plot on the slope, classified into one of four broad classes based on relative vertical distance above permanent stream (figure 4.3).

a. Lower slope--In mountainous, plateau, hill and bluff areas, from streambank, including bottom land, to one-quarter

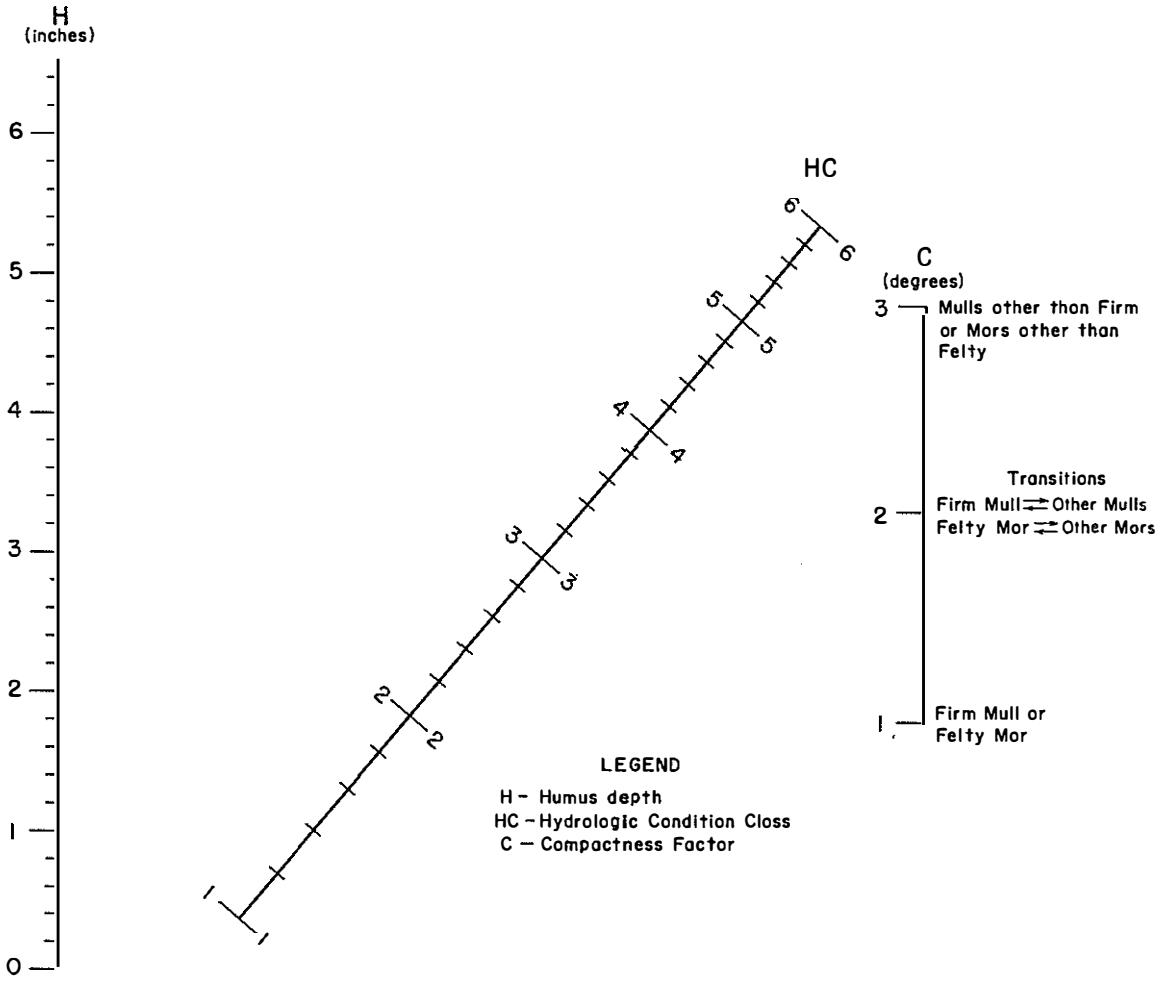


Figure 4.1 - Chart for determining present hydrologic condition of forest and woodland.

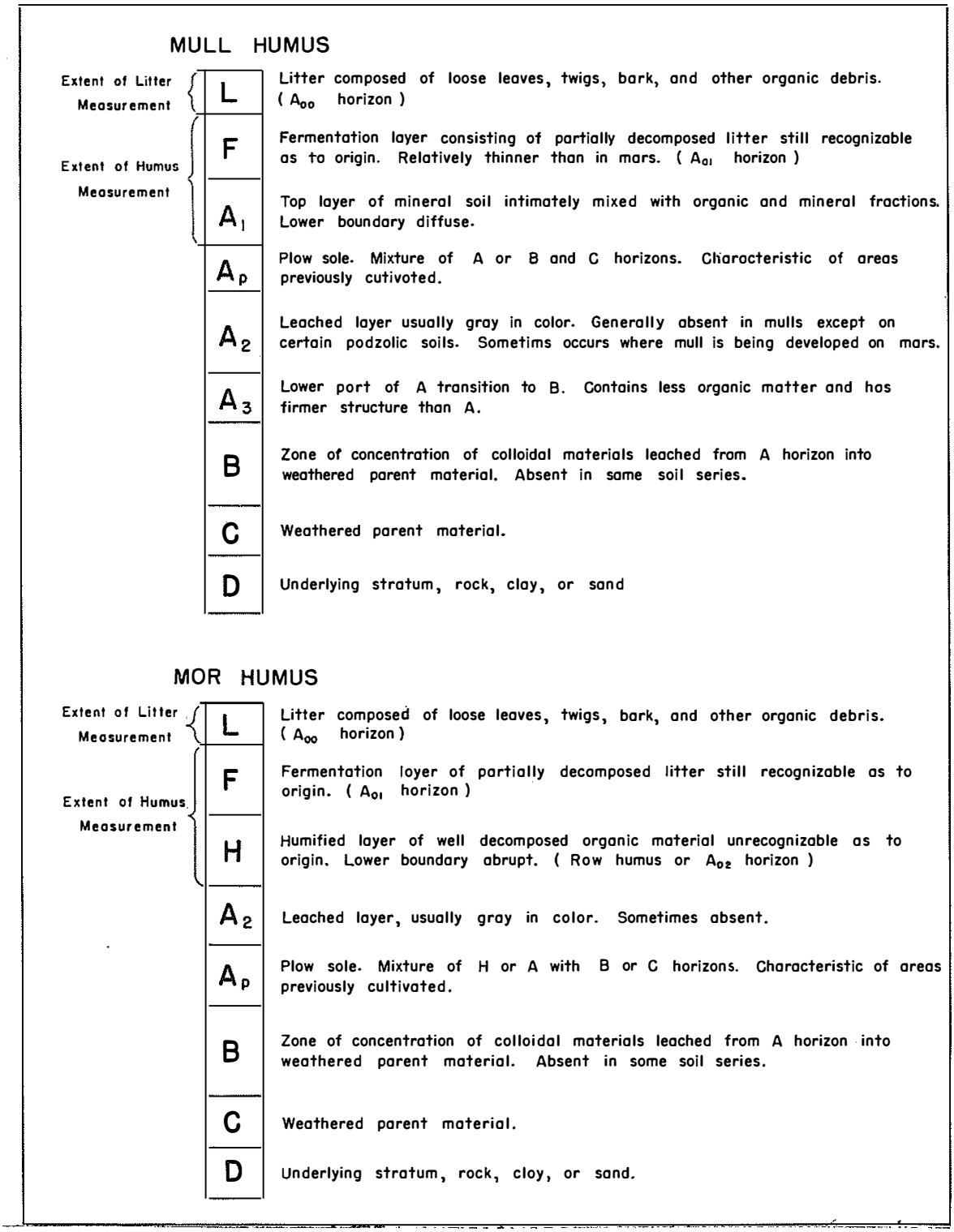

MULL HUMUS
Extent of Litter Measurement
Extent of Humus Measurement
L
Litter composed of loose leaves, twigs, bark, and other organic debris. (A_{oo} horizon)
F
Fermentation layer consisting of partially decomposed litter still recognizable as to origin. Relatively thinner than in mars. (A_{o1} horizon)
A_1
Top layer of mineral soil intimately mixed with organic and mineral fractions. Lower boundary diffuse.
A_p
Plow sole. Mixture of A or B and C horizons. Characteristic of areas previously cutivoted.
A_2
Leached layer usually gray in color. Generally absent in mulls except on certain podzolic soils. Sometims occurs where mull is being developed on mars.
A_3
Lower port of A transition to B. Contains less organic matter and hos firmer structure than A.
B
Zone of concentration of colloidal materials leached from A horizon into weathered parent material. Absent in same soil series.
C
Weathered parent material.
D
Underlying stratum, rock, clay, or sand
MOR HUMUS
Extent of Litter Measurement
Extent of Humus Measurement
L
Litter composed of loose leaves, twigs, bark, and other organic debris. (A_{oo} horizon)
F
Fermentation layer of partially decomposed litter still recognizable as to origin. (A_{o1} horizon)
H
Humified layer of well decomposed organic material unrecognizable as to origin. Lower boundary abrupt. (Row humus or A_{o2} horizon)
A_2
Leached layer, usually gray in color. Sometimes absent.
A_p
Plow sole. Mixture of H or A with B or C horizons. Characteristic of areas previously cultivated.
B
Zone of concentration of colloidal materials leached from A horizon into weathered parent material. Absent in some soil series.
C
Weathered parent material.
D
Underlying stratum, rock, cloy, or sand.

Figure 4.2 - Relative positions of humus layers in soil profiles of forested areas

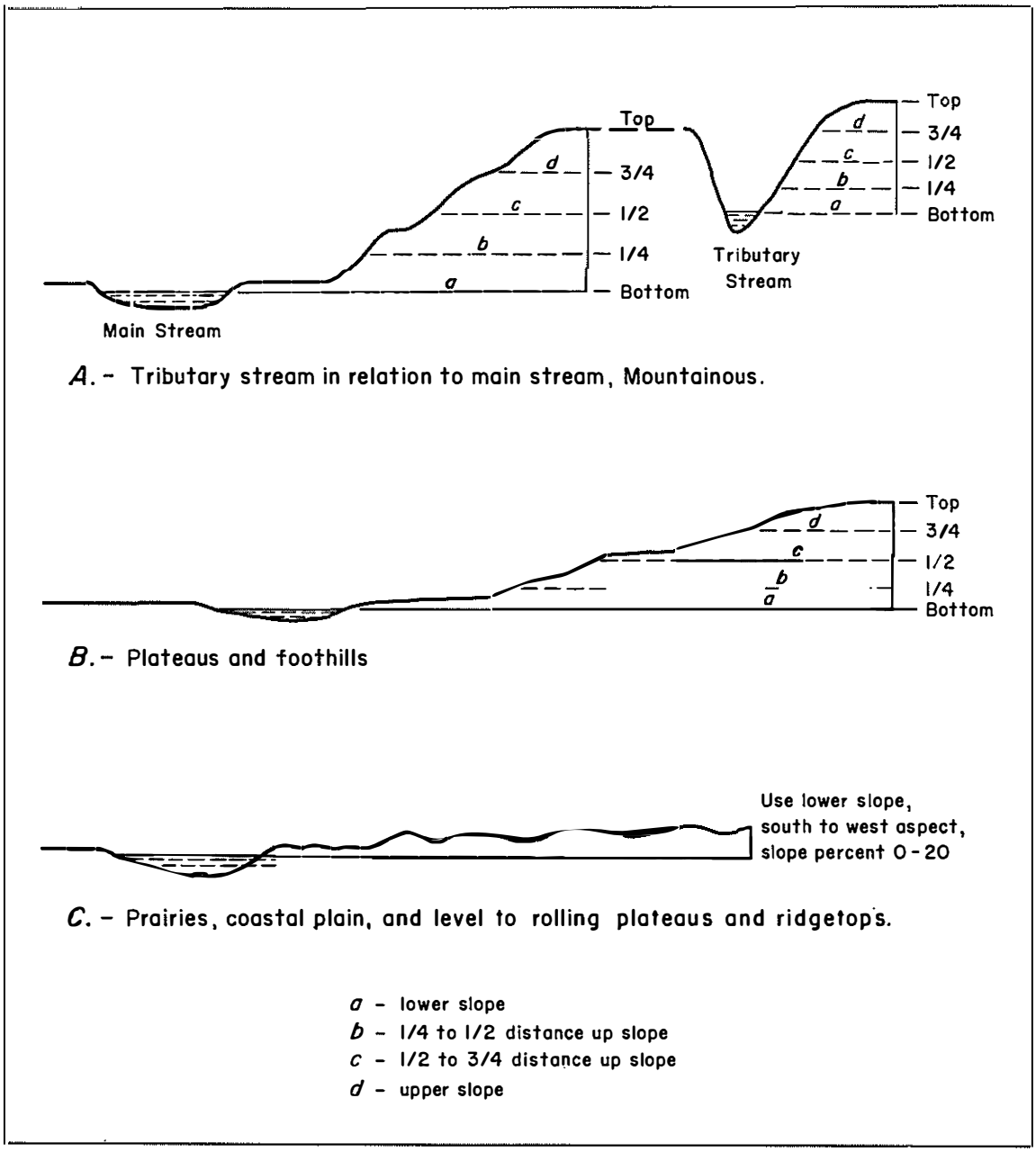

Top
d
3/4
c
1/2
b
1/4
a
Bottom
Main Stream
Tributary Stream
A. - Tributary stream in relation to main stream, Mountainous.
B. - Plateaus and foothills
Use lower slope, south to west aspect, slope percent 0 - 20
C. - Prairies, coastal plain, and level to rolling plateaus and ridgetops.
a - lower slope
b - 1/4 to 1/2 distance up slope
c - 1/2 to 3/4 distance up slope
d - upper slope

Figure 4.3 — Examples of slope position

Table 4.1--Land Factors and Forest Hydrologic Condition Improvement Potential

Aspect	Soil Class	Soil Depth Inches	Lower Slope (Streambank to ¼ distance up slope) Slope percent 0-20	21-40	41+	¼ to ½ distance up slope Slope percent 0-20	21-40	41+	½ to ¾ distance up slope Slope percent 0-20	21-40	41+	Upper Slope ¾ distance to top of slope) Slope percent 0-20	21-40	41+
North to East	Clays	13-24	H	H	M	H	M	M	M	M	L	M	L	L
		25+	H	H	H	H	H	H	H	H	M	H	M	M
	Loams	13-24	H	H	H	H	H	M	H	M	M	M	M	L
		25+	H	H	H	H	H	H	H	H	H	H	H	M
	Sands	13+	H	M	M	M	M	L	M	L	L	L	L	L
South to West	Clays	13-24	M	M	L	M	L	L	L	L	L	L	L	L
		25+	H	M	M	M	M	L	M	L	L	L	L	L
	Loams	13-24	H	M	M	M	M	L	M	L	L	L	L	L
		25+	H	H	H	H	H	M	M	M	M	M	M	L
	Sands	13+	M	L	L	L	L	L	L	L	L	L	L	L
Northwest & Southeast	Clays	13-24	H	M	L	M	M	L	M	L	L	L	L	L
		25+	H	H	H	H	M	M	H	M	L	M	M	L
	Loams	13-24	H	H	M	H	M	M	M	M	L	M	L	L
		25+	H	H	H	H	H	H	H	H	M	H	M	M
	Sands	13+	M	L	L	M	L	L	L	L	L	L	L	L

For ridge tops narrower in width than two chains, use South to West, Upper Slope.
For level to rolling prairie areas, use South to West, Lower Slope, Slope percent 0-20.

H -- High hydrologic condition improvement potential
M -- Moderate hydrologic condition improvement potential
L -- Low hydrologic condition improvement potential

distance up slope to ridgetop. All rolling prairie and coastal plain areas.

b. One-quarter to one-half distance up slope--applies only to mountainous, plateau, hill, and bluff areas.

c. One-half to three-quarters distance up slope--applies only to mountainous, plateau, hill, and bluff areas.

d. Upper slope--applies only to mountainous, plateau, hill, and bluff areas from three-quarters distance up slope from streambank to and including ridgetops.

Illustrations of the determination of forest hydrologic condition improvement potential for (1) prairie, and (2) mountainous areas are given below:

a. Prairie Woodland Area.

Topography--Rolling.

Soil--Carrington loam, depth exceeding 25 inches (Group B). Situation as illustrated in figure 4.3. As instructed in table 4.1, use lower slope, south to west aspect, and slope percent of 0 - 20. The hydrologic condition improvement potential would be "H" (high).

b. Mountainous Area.

Aspect--Indefinite.

Soil--Dekalb stony silt loam (Group B), 19 inches to bedrock.

Slope location--Ridgetop less than two chains in width.

Percent of slope--0.

Situation as illustrated in figure 4.3. As instructed in table 4.1, use south to west, upper slope. The hydrologic condition improvement potential would be "L" (low).

c. Mountainous Area on Small Tributary Stream.

Aspect--NE.

Soil--Dekalb stony silt loam (Group B), 20 inches to bedrock.

Slope location--Ridgetop wider than two chains.

Situation--Similar to figure 4.3. Using table 4.1 direct. Hydrologic condition improvement potential would be "M" (medium).

2. Rate of Hydrologic Condition Improvement. The rate at which the hydrologic condition of a forest area is improved, providing the ultimate hydrologic condition for the site has not been attained, depends upon the use and treatment given the area. With the installation and maintenance of good forest management practices the rate of improvement in forest hydrologic condition can generally be accelerated considerably over that without management.

The measures necessary for attaining the accelerated rate of improvement include: (1) protection from fire, grazing, overcutting, damaging logging, and epidemics of disease and insects which endanger forest cover, (2) tree planting in open fields, woods' openings, or as a phase of hydrologic stand improvement to induce stand conversion necessary for accelerating the improvement of hydrologic condition, (3) hydrologic stand improvement for the establishment and maintenance within the stand of hydrologically desirable species or for the improvement of soil conditions necessary for accelerating the improvement of hydrologic condition.

The rates of improvement of forest hydrologic condition under good forest management and protection, which involve the measures listed above and starting with bare soil, are shown by hydrologic condition improvement potential classes in figure 4.4.

3. Determination of Future Forest Hydrologic Condition With Needed Program. Future forest hydrologic condition based on the installation of all the forest management and protection measures needed to improve and maintain hydrologic condition at a high level is determined as follows:

On figure 4.4, enter the appropriate hydrologic condition improvement potential curve at the present hydrologic condition class. Read years on time scale and add to this value the number of years equal to one-half the evaluation period. (This is done in order to get the average future condition during the evaluation period. In a 50-year-evaluation period, 25 years would be used). Read back on the appropriate forest hydrologic improvement curve to 0.1 hydrologic condition class. An illustration of this procedure is given below:

Present hydrologic condition class--1.3; hydrologic condition improvement potential--high. Using figure 4.4, enter high HCIP curve at forest hydrologic condition class on high HCIP curve at 31 years, obtaining future forest hydrologic condition class of 3.4.

From figure 4.5, class 1.3 = curve number 58 (soil A), on figure 4.6 runoff equals 4.6 inches with 10-inch rain.

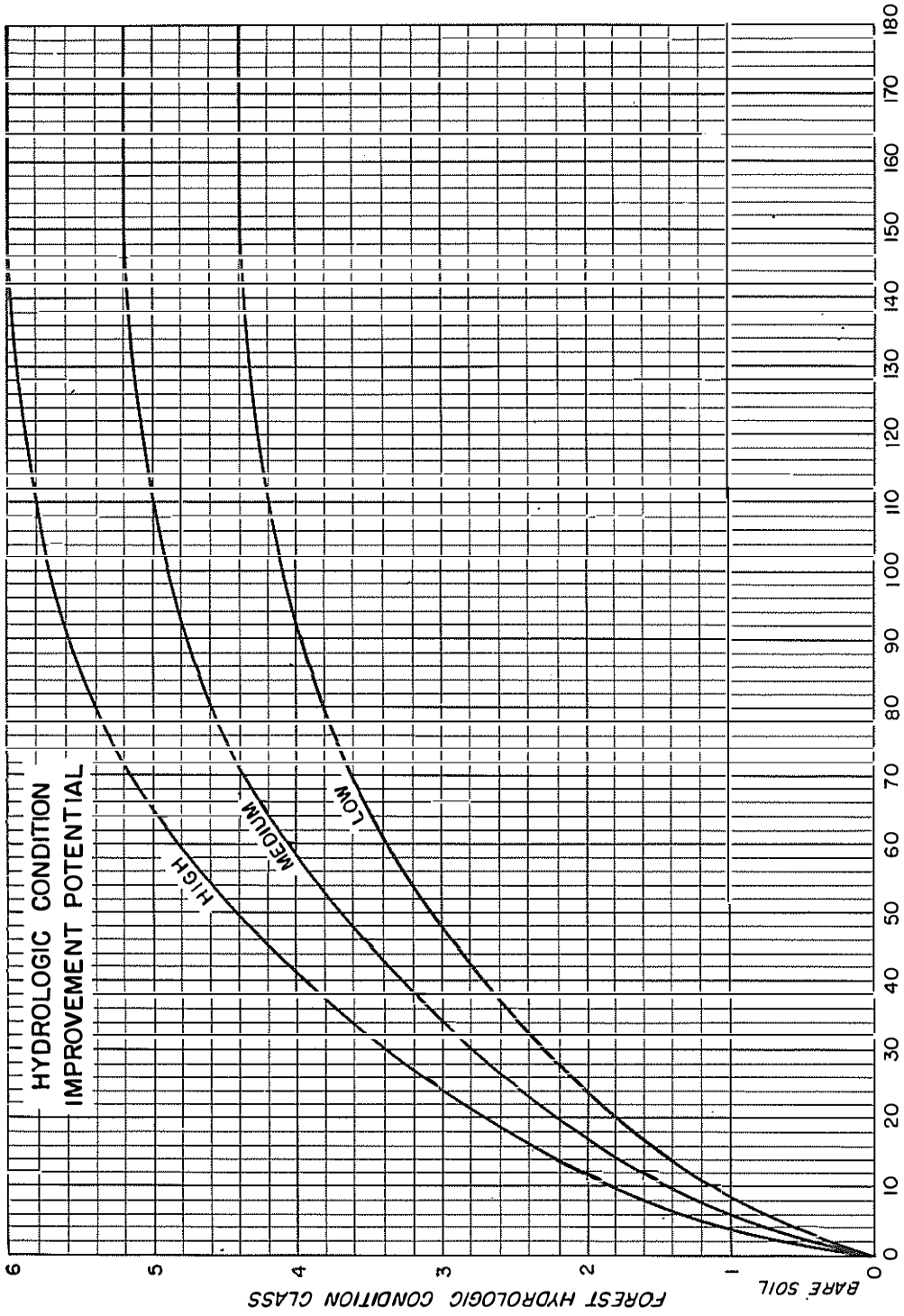


Figure 4.4 - Rate of Improvement of Forest Hydrologic Condition Under Management. Starting Condition - Bare Soil

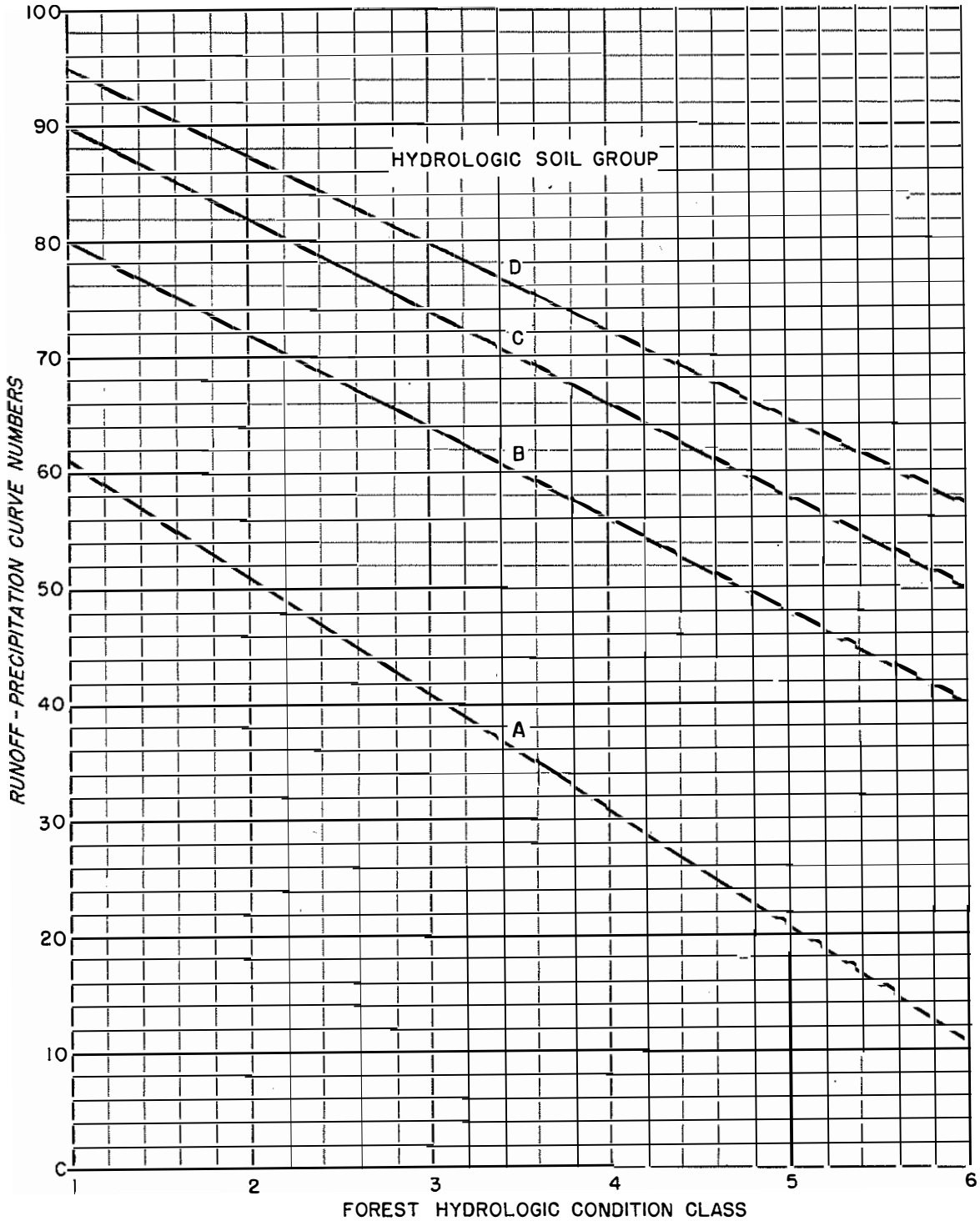


Figure 4.5 – Runoff–Precipitation Curve Numbers by Hydrologic Soil Group and Forest Hydrologic Condition Classes for Antecedent Moisture Condition II.

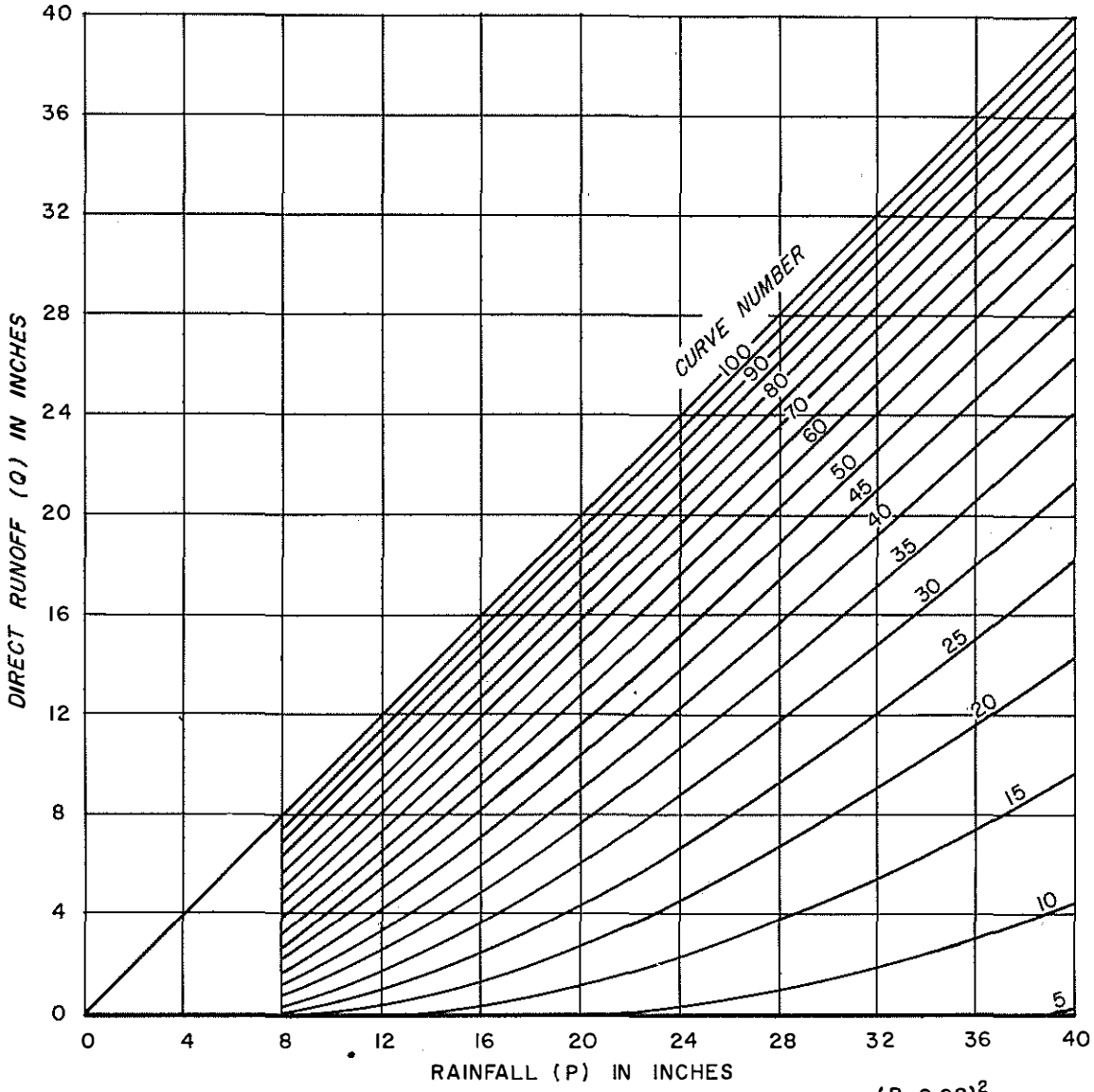


Figure 4.6 – Solution of Runoff Equation $Q = \frac{(P-0.2S)^2}{P+0.8S}$
from Soil Conservation Service

From figure 4.5, class 3.4 = curve number 37 (soil A), on figure 4.6 runoff = 1.9 inches with 10-inch rain.

Sources of data to supplement and expand watershed hydrologic condition surveys:

Forest Survey. One phase of the forest survey conducted by the Division of Forest Economics is the collection and compilation of basic information on forest land area, timber volume, growth and mortality drain, requirements, growth goals, ownership, and other related information.

Data collected by the Forest Survey which is correlated with the hydrologic condition of the forest-floor varies by regions and by surveys within the regions. In general, Forest Survey provides such information as:

a. Tables and maps, showing the area of land classified according to the nature of its use, such as:

(1) Forest land, classified into major forest types, age, stocking, and topographic descriptions such as uplands, lowlands, river bottoms, etc.

(2) Other areas such as agriculture land, deforested areas, nonforested, and noncommercial rocky timbered areas, prairies, levees, roads, railroads, towns, and waterways.

b. Tables of timber volume, showing the board-foot and cubic-foot volume of the present stands, classified by species groups, for forest conditions and by principal forest types.

c. Tables of timber growth by forest conditions and species groups.

d. Stand and stocking tables, showing the number of trees by species, and diameter classes for the forest conditions.

Forest Survey data can be used for determining the hydrologic condition of a watershed. However, a correlation must first be established between the measured hydrologic condition from the watershed field survey and the index of the hydrologic condition as measured by the Forest Survey. An example of application would be the correlation of hydrologic condition with the timber volume in the same physiographical area. Such a correlation, if significant, allows for estimating hydrologic condition in the area when the timber volume has been determined. Future timber volume as expected under different levels of forest management reflects the future hydrologic condition. Another example is when a flood control survey in the West used Forest Survey data to obtain the density and age of the forest stand. Cover density

weighed by age can be correlated with flood runoff and used to evaluate the effects of a land treatment program.

4.3 - Example. This is an example of a guide for field plot examination of forested areas in small watershed surveys. Approximately fifty primary forest plot locations for each subwatershed are selected on aerial photomosaics (or on county maps and contact prints), using a systematic grid. In addition, a secondary plot is taken five chains north of each of the primary plot locations, or clockwise in a cardinal direction so as to fall in a forested area.

The plot grid is laid out in the office on aerial photos which in some cases are several years old or are too small or of too poor quality to be clear. Consequently, when located on the ground, occasional plots will fall in an area that does not meet the definition of forest land. When this happens, if there is forest land within 10 chains of the point, the surveyor should go directly toward it, and continue in the same direction for 2 chains into the forest, to locate the plot. If the forest type is less than 4 chains but more than 120 feet in width, the plot should be located midway. Instead of 2 chains distance, the plot should be located midway in the forest if the type is less than 4 chains but more than 120 feet wide.

All data except hydrologic condition and cruise data will be obtained on a 1/4-acre circular plot (radius 58.88 feet), and reported on a form similar to table 4.2.

Use of Card Form--Table 4.3. The card is designed for field use. Records will be a combination of pencil work and punching. It is suggested that insofar as possible the pencil work be done first because the card becomes more fragile as the edges are punched. It is important that the cards be kept in good condition to facilitate sorting for compilation and analysis in the office.

The card is designed for simple, easy recording and subsequent sorting for compilation with only a simple punch and a knitting needle. The procedure is to notch out the margin in the appropriate spaces so that when a needle is inserted through a certain hole in a group of cards the ones with the margin cut out at that point will drop out of the deck. The system is very convenient for use with relatively simple data and will not only greatly speed up the compilation procedure and increase accuracy but will make it possible to test for correlations between various factors in a manner that was almost impossible before.

Hydrologic Condition: (Field Observations). The primary reason for the field survey is to determine the hydrologic condition of forest lands. The process consists of several related steps. Generalized information gained from observations on and surrounding the 1/4-acre plot are merged with data gained from close observations of litter and humus depth on 3 mil-acre subplots.

Table 4.2

Forest Hydrologic Conditions and Cruise Data Sheet

Remarks: _____

Watershed ____ ____ Date _____
Unit _____ Recorder _____
County _____ Plot No. _____

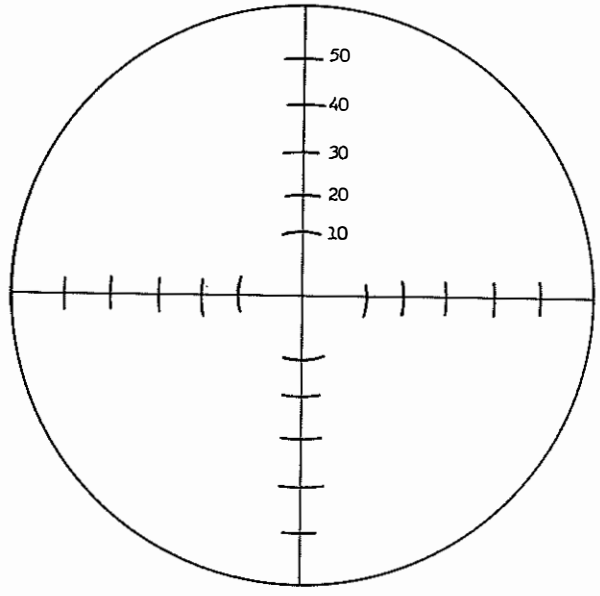
Forest Condition

- Forest Type.....
- Stand Quality.....
- Stand Size.....
- Stocking.....
- Canopy.....
- Repod. Density Class.....
- Slope.....
- Exposure.....
- Site.....
- Fire Occurrence.....
- Fire Damage.....
- Grazing.....
- Logging Practice.....
- Ownership.....
- Sheet Erosion.....
- Seed Source.....
- Interplanting Need.....
- Pine Release.....
- Stand Conversion.....
- Timber Stand Imp.....
- Insect end Disease.....

Hydrologic Condition

- Forest Floor
  - Distribution %.....
  - Depth inches.....
- Depth of A1 Layer.....
- Structure-Surface 6".....
- Hydrologic Condition.....

1	2	3	Ave.



Cruise Data

Pulp	Tally				
			SC		
Feet	P	H	P	H	RC
0					
10					
20					
30					
40					

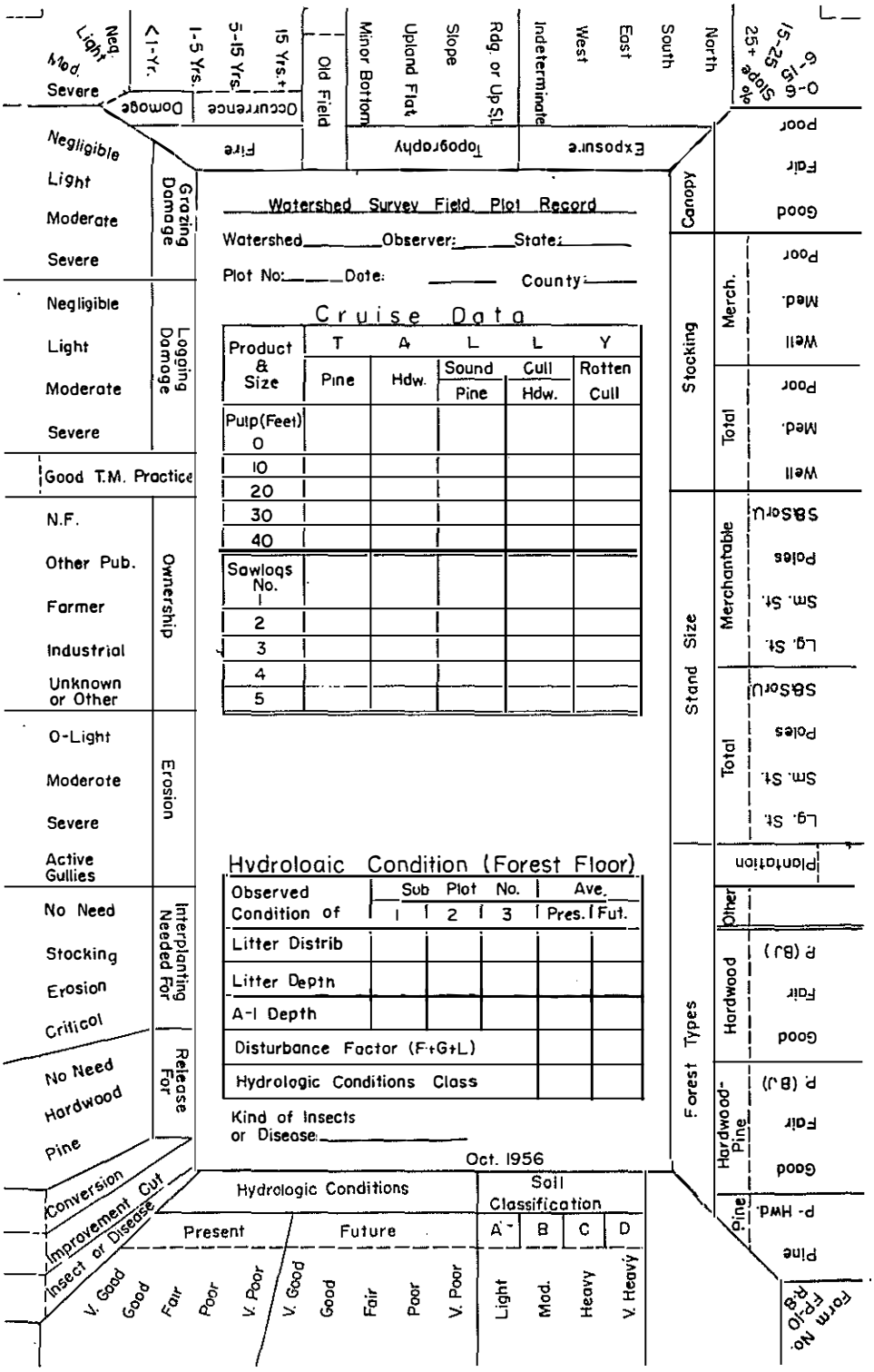
Logs	Tally				
			SC		
#	P	H	P	H	RC
1					
2					
3					
4					
5					

Witness Trees

Species	DBH	Azimuth	Distance

Table 4.3

Hydrology Form--Forest Condition Survey (IBM)



Subplots are intended to direct careful attention to the condition of the forest floor and to promote an unbiased estimate of the average amount and condition of the litter and humus on the 1/4-acre plot as represented by the 3 mil-acre subplots (3.7-foot radius). These subplots should be examined and rated before the observers cause appreciable disturbance in the area. One subplot is located at the main plot center, one 25 feet north, and the other 25 feet south of the plot center. Order of observing or numbering the subplots is unimportant.

Procedures for Computing Present and Future Hydrologic Conditions. The following computations can be done in the office after the litter depths have been recorded and the fire, grazing, and logging factors have been rated and punched in the field. Disturbance factor is computed on the basis of the damage ratings punched in the field for fire, grazing, and logging according to the following table which gives numerical values that can be added to give a relative disturbance factor.

	Fire	Grazing	Logging
Negligible	1	1	1
Light	2	3	2
Moderate	3	5	3
Severe	4	7	4

When this total disturbance factor equals 3 to 6 the degree of disturbance is classed as negligible, when the total is 7 or 8 the degree is moderate, and when 9 to 15 the degree is severe. These classes should agree rather well with the loose, moderate, and compact humus types as rated in the field. Then by using the following table the average depth of humus and litter can be matched with the degree of disturbance to determine the hydrologic condition class.

Litter (L + F) (depth in inches)	A (Humus + A_1) (depth in inches)	Hydrologic Condition Class		
		Negligible (3-6)	Moderate (7-8)	Severe 9+
0+	0-0.49	P (II)	VP (I)	VP (I)
0-0.99	0.5-0.99	P (II)	P (II)	VP (I)
1+	0.5-0.99	F (III)	P (II)	VP (I)
0+	1.0-1.49	F (III)	P (II)	VP (I)
0-0.99	1.5-1.99	F (III)	F (III)	P (II)
1+	1.5-1.99	G (IV)	F (III)	P (II)
*0+	2.0-4.99	G (IV)	F (III)	F (III)
*0+	5.0+	VG (V)	G (IV)	F (III)

* When less than 0.2 inch, drop hydrologic condition 1 grade.

Rating Hydrologic Damage Due to Disturbances Such as Fire, Grazing, or Logging. These damages should be classified primarily on the basis of damage to hydrologic conditions, but to some extent it may be necessary to consider evidence of damage to the forest stand to evaluate the hydrologic damage. In evaluating damages, from either fire, grazing, or logging on old fields the probable time since last cultivation should be considered, as well as the possible effects of the other current damage factors. For example, in a 15-year-old stand of pine, the lack of significant A_1 development should not all be attributed to fire even though there is evidence of fire having passed through because there has not been time enough for much humus development even without fire. The fire has retarded development of good hydrologic conditions and therefore has caused damage, but should not be rated more severely than warranted.

Fire Damage. When fire has not occurred within the past 15 years, fire damage would seldom be rated worse than light, even though many trees may show old-fire scars. It must be remembered that effect of fire or other factors is reflected by the measurements of litter and A_1 depth and therefore their detrimental effects upon soil development enter into the formula for determining hydrologic condition in this way also. Moderate or severe fire damages are generally associated with recent fires, bare or puddled soil, or evidence of fire-induced erosion. Repeated past fires, though stopped during the last few years, may also justify moderate or severe damage rating in spite of a light accumulation of litter and fair stability. Fires hot enough to kill many of the trees or reproduction thus opening up the canopy and baring the soil do severe damage that may last for many years.

Grazing Damages. Grazing damages to the hydrologic condition of the forest soil are frequently more serious and longer lasting than is generally realized. When plants have made a few months' growth since last grazed, it is easy to overlook signs of grazing and to underrate the damage. Look for trails, cow dung, signs of browsing on reproduction, shrubs and vines, high-lining on young pines and cedar, lack of reproduction, etc. Generally, the "negligible" rating should be used only when no signs of grazing can be found. A few scattered signs of current use of the more palatable species, or old, presently unused trails would justify a "light" damage rating. Obvious use of more palatable species and signs of trailing and trampling with some bare soil indicate moderate damage. Considerable bare ground, obvious trampling, heavy browsing, and shortage of undergrowth and sheet or more severe erosion obviously attributed to grazing are signs of severe damage.

Logging Damage. Logging damage to hydrologic values varies considerably depending on topography, logging methods, and other factors. A logging job that might be very poor silviculturally still might not seriously harm the hydrologic conditions. The two objectives should not be

confused. Clear-cutting, which opens the canopy unduly and thus promotes rapid oxidation of the litter and humus, may be temporarily harmful hydrologically, though in some cases it may be recommended silviculture. Erosion induced by skid trails or logging roads, or compaction caused by trucks or other equipment are other examples of damage to hydrologic values. These damages are always associated to some extent with logging, but are generally localized. The seriousness of damage depends upon how widespread these damages are and sometimes upon what has been done to prevent erosion.

Erosion. Rate on the basis of current condition in regard to visible signs of erosion or erosion potential in case of recent disturbance, such as fire or logging. "Hone to light" is for situations where there is very little or no erosion as when the soil is almost completely protected by vegetation or litter, generally less than 5 percent bare soil. "Moderate" erosion is obvious but has not reached and probably will not reach a stage that would be difficult and expensive to control. It might include situations that have been worse, but are gradually healing and are nearly stabilized. A new light burn that might be expected to erode some for a year or two but to stabilize rather rapidly without special treatment might classify as "moderate" even though there has been no erosion at time of observation. The same would be true in the case of recent logging disturbance that threatens to cause erosion for a time. Moderate sheet erosion may commonly be associated with 5-25 percent of bare soil. Sheet erosion beyond the moderate class should be rated as "severe." Signs of severe erosion are small rills; erosion pavement; pedestals under small rocks, plants, twigs, etc.; more than 25 percent of the ground exposed to erosion; revegetation or other measures probably needed to promote healing. In classifying erosion potential, consider such factors as slope, aspect, soil, amount and kind of cover, time since disturbance, signs of natural stabilization, action already taken to counteract erosive tendency, and other factors that may be pertinent.

Soil Classification. Soil on each plot will be classified according to SCS hydrologic soil groups. "Group A" consists of light soils that have a minimum impediment to downward movement of water. The entire solum has a very low content of clay. (Deep loose sand to loamy sand would be typical of this group.) "Group B" includes medium textured soils somewhat less permeable than "A" but still with rather high infiltration and percolation rates, probably sandy loams to loams, "Group C" soils are heavy and have still less permeability, probably ranging through silty loams to silty clay loams. "Group D" includes the very heavy soils with very low permeability and is characterized by a high clay content, such as silty clay, sandy clay, and clay.

These textural guides are not the only criteria for classifying soils into hydrologic groups and are intended only as a beginning. Other factors such as organic content, soil depth, and drainage also affect intake rate and should be considered. Observers should try to get some additional field training in this regard from qualified soils technicians who are familiar with the system.

EFFECT OF LAND TREATMENT

CHAP. 5

CHAPTER 5

5 - EFFECT OF LAND TREATMENT

5.1 - Principles of Evaluation. The methods used to evaluate the effects of the land treatment programs upon flood flows will vary considerably with the type of flood, since different approaches are needed for various flood-producing events. Local summer rains, general storms, or snowmelt occurring singly or in combination, are the three principal climatic events which may result in flood or sediment damage.

1. Effect of Land Treatment During Local Summer Storms. Storms of high intensity very often produce local floods from overland flow. Since the area covered by intense rainfall is quite limited, few records have been obtained of these storms or of flood damages. At few places in the country is the network of either rain or stream gages sufficiently dense to measure the characteristics of these storms or floods. Considerable research, however, has been conducted on the effect of cover conditions upon the runoff from this type of storm.

All records available from recording gages in or near the problem area are studied. Several storms of various magnitudes are selected for design purposes. Few intense summer storms of any great depth have ever been measured at the recording gages reporting to the U. S. Weather Bureau. However, an average pattern can usually be developed for the 1- and 2-inch depths with durations less than 1 hour; table 5.1. The typical pattern of infrequent thunderstorms can be taken from studies by the Weather Bureau, (fig. 5.1).

In order to compute overland flow from the above storms, estimates of infiltration rates into the soil as influenced by vegetal cover have been compiled from plot tests by the Forest Service Experiment Stations. Several hundred infiltrometer tests have been made on forest and rangeland with similar cover and soil conditions elsewhere in each region. Final infiltration capacities from all available tests can be classified by soil texture and depth, plant-cover type, and ground-cover density, (figure 1.5, chapter 1). Overland flow for various condition classes of plant cover by soil groups is computed for each of the design storms.

The present physical condition of rangelands within the drainage basin is sampled on small tributaries by field surveys. Each tributary is subdivided into parts based on a soils-cover stratification (chapter 3 - 3.1) to apply the results from infiltration plots and experimental watersheds. The field description of each subarea also estimates the future ground-cover density expected with a program.

Overland flow can be computed for each subarea based on present cover conditions on each tributary watershed, 5.4, item (3). Future runoff with the land-treatment program in effect is also

computed for the changed cover conditions. Estimates of potential flood reductions are obtained by comparing the present and future runoff from these small local storms equivalent to unit hydrograph floods.

Table 5.1--Local Design Storms - Western States[1]
(One hour, 100 - Yr.)

Washington		Idaho	
Cascades	2.5 x .7 = 1.75"	Central	2.5 x .4 = 1.0"
Olympic	2.0 x .8 = 1.60	Southwest	3.0 x .4 = 1.2
Inland	3.0 x .4 = 1.20	North	2.5 x .5 = 1.25
		Southeast	2.0 x .6 = 1.2
Oregon		Nevada	
Coastal	2.5 x .9 = 2.25"	Great Basin	3.0 x .4 = 1.2"
Cascades	2.5 x .6 = 1.50		
Owyhee	3.0 x .4 = 1.20	Montana	
California		Northwestern Mountain	2.5 x .5 = 1.25
Shasta	2.5 x .9 = 2.25"	Utah	
Central	2.0 x 1.0 = 2.00		
Los Angeles	2.5 x 1.2 = 3.00	North	2.5 x .7 = 1.75
		South	3.0 x .7 = 2.10
Arizona		Wyoming	
Prescott	3.0 x 1.1 = 3.3"	Northwest	2.5 x .8 = 2.0
Santa Rita	2.5 x 1.4 = 3.5		
New Mexico		Colorado	
		East Slope	3.0 x 1.1 = 3.3
Riodoso	2.5 x 1.5 = 3.75"	Cripple Creek	2.8 x 1.2 = 3.3

[1] Weather Bureau "Rainfall Intensity for Local Design in West," Technical Paper No. 28, 1956.

2. Effect of Watershed Management During General Storms. General storms cause floods of considerable magnitude and frequency. In some regions major floods from this source occur only at infrequent intervals. Melting snow in combination with rain may add to these floods and frozen ground may also be a contributing factor.

Precipitation totaling up to about 30 inches has caused some of these floods, as listed in storm studies by the Corps of Engineers. Hourly intensities at recorders operating during general storms have usually been rather low. Therefore, the problem is one of soil storage capacity rather than a limiting infiltration rate. Runoff records on many streams show that several inches of runoff over a period of several days occurs during these damaging floods.

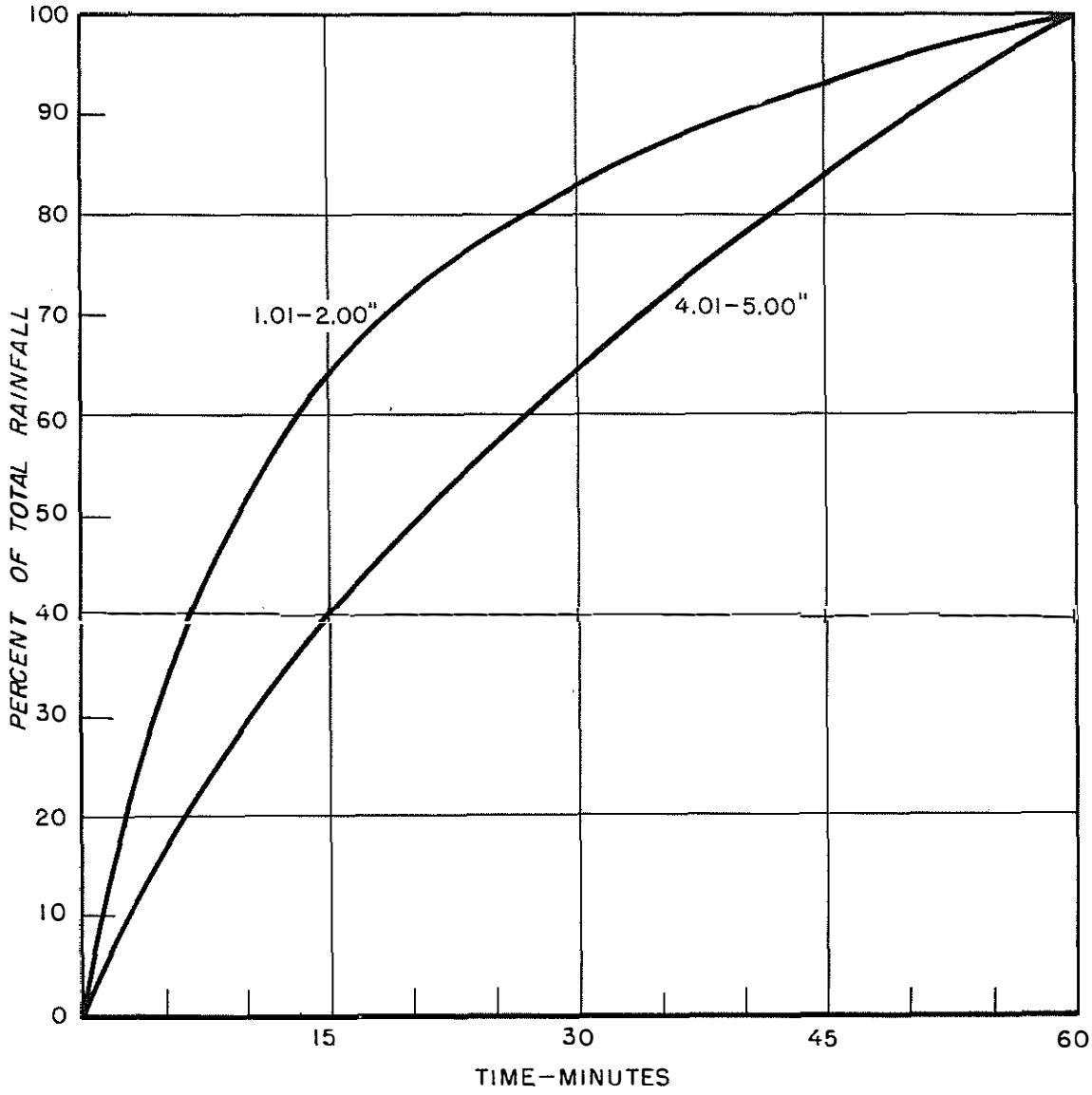


Figure 5.1 – Typical Mass Curves, U.S.W.B.

Table 5.2

Example--Soil Properties Used To Compute Runoff (Rain = 2.0"/hr.)

Profile Depth	Profile Texture	Inflow (in./hr.) Rainfall	Storage (inches) Detention	Storage (inches) Retention	Outflow (in./hr.) Percolation	Outflow (hours) Time	Runoff ("/hr.)
	Interception	2.00"	.05"		-.15"		
	Evapo-transp.			.23"			
	Depressions		.02			1 hr.	
1" H	Litter, Humus		.10	.20		1 hr.	
0"	Infiltration		Wet = .5	Dry = 3.0	Av. = 1.0	Initial Losses	= .45"
	Sandy	1.55"		--		1 hr.	0
A_0		1.92			-1.00	2 hr.	.92
		1.92	-0.5			3 hr.	1.42
6"	Loam	1.55(Dry)	--	-1.55*			↑ Over-land Flow
A_1		1.00	-1.00*		0.0		
		0.50	--		-0.5*		
12"	Loam	0.50		-.50*		4 hr.	1.42↓
A_2		0.50	-.50*			5 hr.	1.42
		0.50			-.50*	6 hr.	1.42
18"	Loam	0.50		-.50	--	7 hr.	1.42
B_1		0.50		-.50	--	8 hr.	1.42
		0.50	-.50		--	9 hr.	1.42
24"	Clay	0.50			-.30*	10 hr.	.20
B_2		0.50			.30	11 hr.	.20
		0.50			.30	12 hr.	.20
30+	Fractured	0.30			0.30*		↑ Subsur-face Flow
C		0.30			0.30		
		0.30			0.30 ←	Ground-water Recharge	

Soil-Cover Water Relations

Profile Depth	Profile Texture	Inflow (in./hr.) Rainfall (P)	Storage (inches) Detention	Storage (inches) Retention	Outflow (in./hr.) Percolation	Outflow (hours) Time	Runoff ("/hr.)
Cover -		Interception	.01-.05 ←	(canopy)	.01-.15 P ←	(stemflow)	
		Evapo-transp.		.01-.23 P			
		Depressions	.01-.02 Q				
H		Litter, humus	.10 H	.20 H			
Surface 0"		(Infiltration) →	Wet	Dry	Average	Initial Losses	↑
A_0	Sandy Loam	High	.5-1.+	3-5+	1-3-+		
		Moderate	.1-.5	1-3	.5-1.0		
		Low	.01-.10	.5-1.0	.1-.5	Overland Flow (Q) →	
Topsoil 6"		(Add Antecedent Moisture)					
A_1	Sandy		2+	0-1	.5-1.5		
	Loam		1-2	1-2	.1-.5		
	Clay		0-1	2+	.01-.10		
12"		(Repeat for lower 6" layers)					
A_2 18"±						Subsurface Flow →	
Subsoil B_1	Sandy		1+	0-1	.3-.5+		
	Loam		.5-1.	1-2	.1-.3		
24"±	Clay		0-.5	2+	.01-.10		
B_2 30"±		(Repeat for lower 6" layers)				Subsurface Flow →	
Rock C	Fractured	High	20-30+		.2-.3+		
	Permeable	Moderate	10-20		.1-.2		
	Imperm.	Low	0-10		.0-.1	Groundwater →	

*Antecedent moisture storage estimated.

Research on plots where soil moisture was sampled provides a basis for estimating the relation of plant-cover conditions to the storage capacities and percolation rates of various textured soils, table 5.2. From these studies soil moisture samples from plots can be used to estimate field capacity and changes in percolation associated with increased organic content of the soil. Depth of litter and duff on forest plots can be found to change with the condition of the cover.

The description of each subarea of the small watersheds enables soil moisture storage to be computed from observations of present soil texture and depth for each condition of cover. Field estimates of future cover conditions with a program can be used to compute the changes in soil storage. The total water stored in the soil on tributary watersheds is computed for several sizes of general storms and amounts of runoff compared for present and future conditions. Flood hydrographs can be computed by routing the water through the soil into ground-water storage and adding the overland flow hydrograph to subsurface flow.

3. Effects of Forests on Floods From Melting Snow. Basic data for the computation of snowmelt runoff hydrographs are (1) snowmelt related to climatic, topographic, and cover variables, (2) losses from evaporation and transpiration, (3) rainfall contributing to stream flow, (4) soil moisture-storage capacity and antecedent deficit, (5) ground-water storage-discharge curves, and (6) routing of channel flows.

Snowmelt can be computed from mean daily temperatures using relations involving the separate effects of aspects, elevations, and seasonal mass temperatures, figure 5.2(a). Rates of melting are determined for large openings and adjusted for conditions within forests. The distribution of the snow cover under forest canopies and in small openings is dependent upon such variables as timber volume, crown density, and total snowfall, figure 5.2(b). For any daily temperature, then, the method is to compute basic open melting rates for each elevation zone and aspect at the appropriate season. These rates apply directly to the area of large openings. Melting rates within forests, classified for aspects and elevation zones by species of trees and age classes, are determined from timber volume and crown density with an interpolation for depth of snowpack. These rates are multiplied by the areas of the various types. Hydrographs are computed by routing present and future snowmelt less losses through ground-water storage (FSH 3502).

However, at the end of this period the lower A and the B horizons were saturated and could transmit water only at the percolation rate of the C horizon.

The next two bursts of rain, lasting 20 minutes, completely utilized the remaining storage space in the humus horizon and surface detention, and more than 1 inch of runoff resulted. Since the humus could then absorb water only at the percolation rate of the C horizon, 1.1 inches of rainfall in the next 40 minutes resulted in about 0.9 inch of surface runoff.

During the next 8 hours a large part of the water temporarily stored in the humus, lower A, and well-drained B horizons drained into the C horizon. This made additional storage space available in these upper horizons. Then several additional bursts of rain caused these horizons to become saturated again and resulted in about 0.2 inch of surface runoff.

For any given storm and its antecedent conditions, there is a definite limit to the total amount of water that can infiltrate into a soil. The maximum limit for a given storm occurs when the humus, lower A, and B horizons are saturated for the duration of the storm and supply water to the C horizon at a constant rate. This condition seldom occurs, because intervals of little or no rainfall generally cause a slackening in the supply of water. These slack periods give the humus and lower A horizons time to drain.

The recovery of detention storage space in the upper soil horizons--as in this example--enables the soil to absorb a series of rainfall bursts (3). Thus the aggregate gain in infiltrated water is far more than the detention.

5.2 - Design Storms and Floods. Storm studies and flood-routing procedures have been developed for general application to any watershed depending upon climatic and drainage-basin characteristics. It is generally desirable, however, to verify estimates of design floods with rainfall and runoff data observed in or near the watershed under study. Sometimes recorded information is too meager to be of much value in establishing local control for general relationships, but exhausting the possible application of local data helps to rationalize the extrapolated estimates.

Recorded flood hydrographs on tributaries are obtained for short-time intervals by reading the original recorder charts of the U. S. Geological Survey when available. Unit hydrographs can be averaged into distribution graphs where time is expressed as a percent of the lag, figure 5.3. This lag is taken as the time difference between the center of the recorded hydrograph and the center of the precipitation excess. For larger drainages the transit time of channel flow from the edge of the storm to the gage must be subtracted from the lag. Rating measurements of velocity of flow by the U. S. Geological Survey at typical channel sections can be used to estimate this travel time.

A similar distribution graph can be derived for small experimental watersheds of the Soil Conservation Service and the Forest Service, figure 5.4. These small flood rises are compared with recording rain gages to give the time lag. It will be noticed that the distribution graphs of all size areas are similar in shape. The time lag for each flood was found to be related to the storm area; when several points were averaged the resulting curves were considered representative of the typical tributary, figure 5.5. These relations based on a limited number of local floods were checked with general unit hydrograph characteristics from other regions, involving slope of the stream, length of major water course, distance to center of area, etc. The agreement between drainage basin lag and unit hydrograph peaks is very close by either method.

Infiltration capacities of various soil and plant cover conditions were determined by the Forest and Range Experiment Stations. These final rates were measured by a 60-minute run after the plots had been prewet. Considerable variation of rates were found due to the density of the ground cover or conversely the extent of bare soil and also differences due to the type of soil, identified by its geologic parent material for convenience.

If a unit hydrograph can be estimated for a definite drainage pattern, then from a series of simultaneously recorded rainfall and runoff rates,

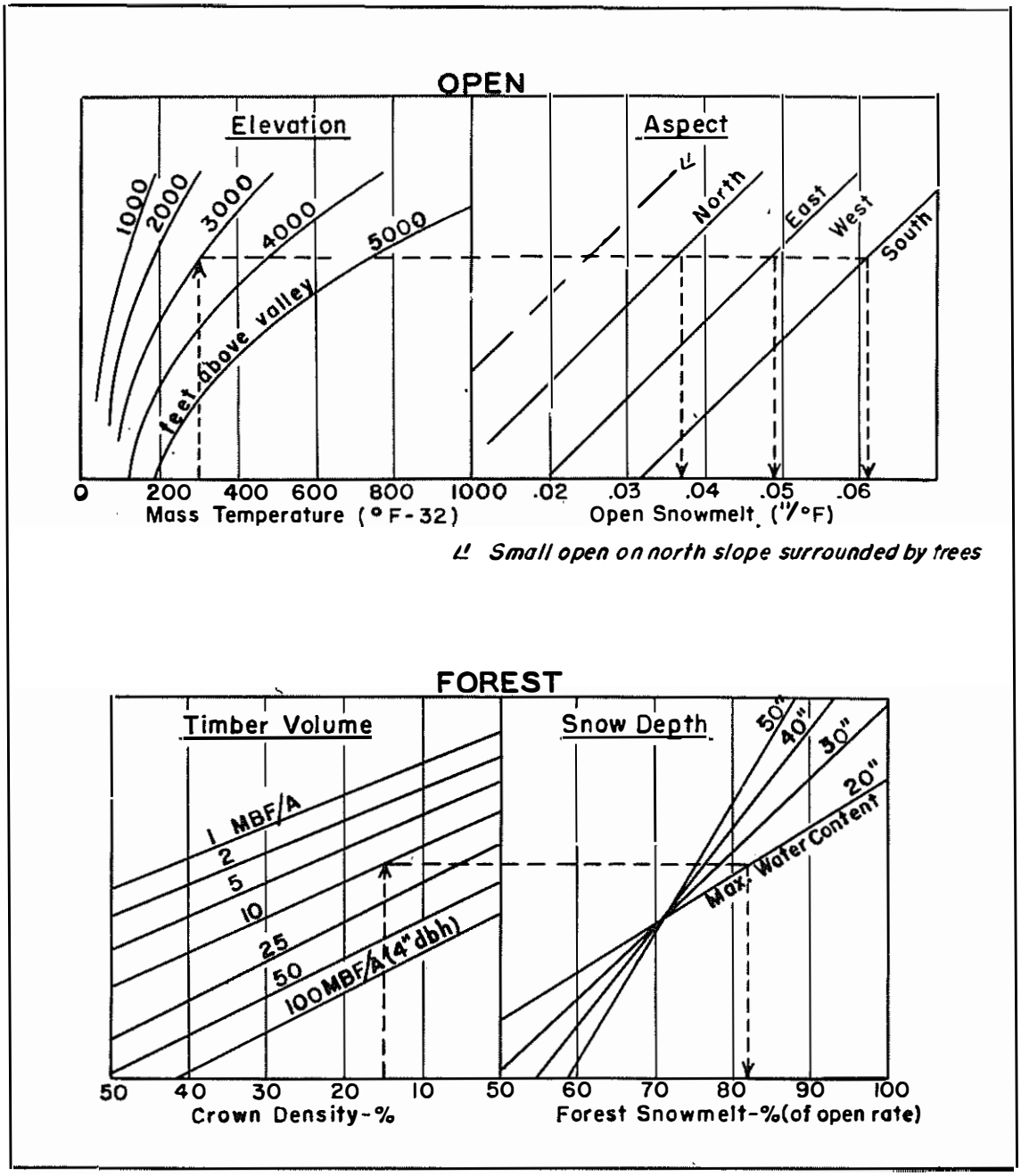


Figure 5.2(a) – Snowmelt in Forest and Open – Idaho, Wyoming, Utah, 1949-1952

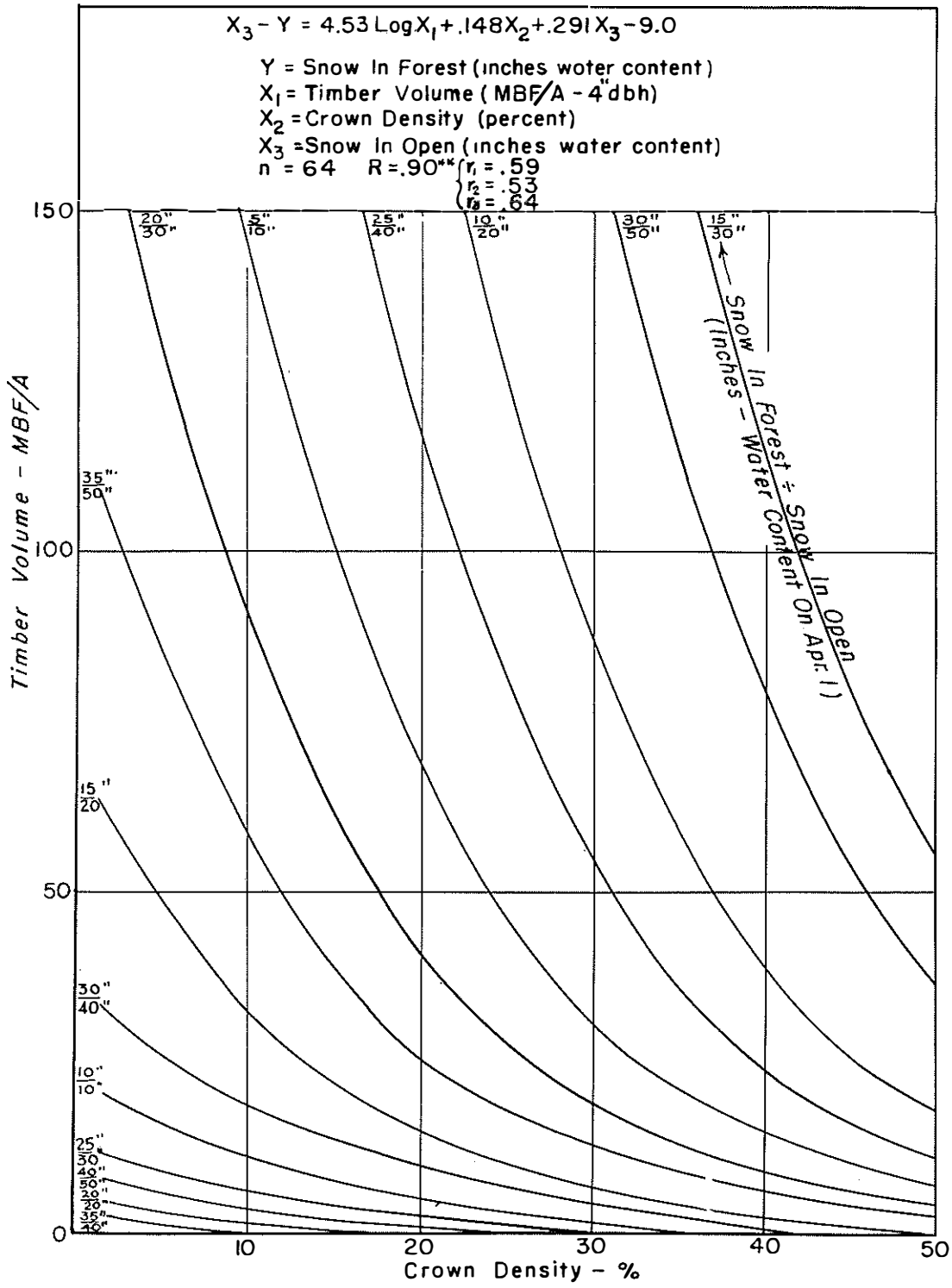
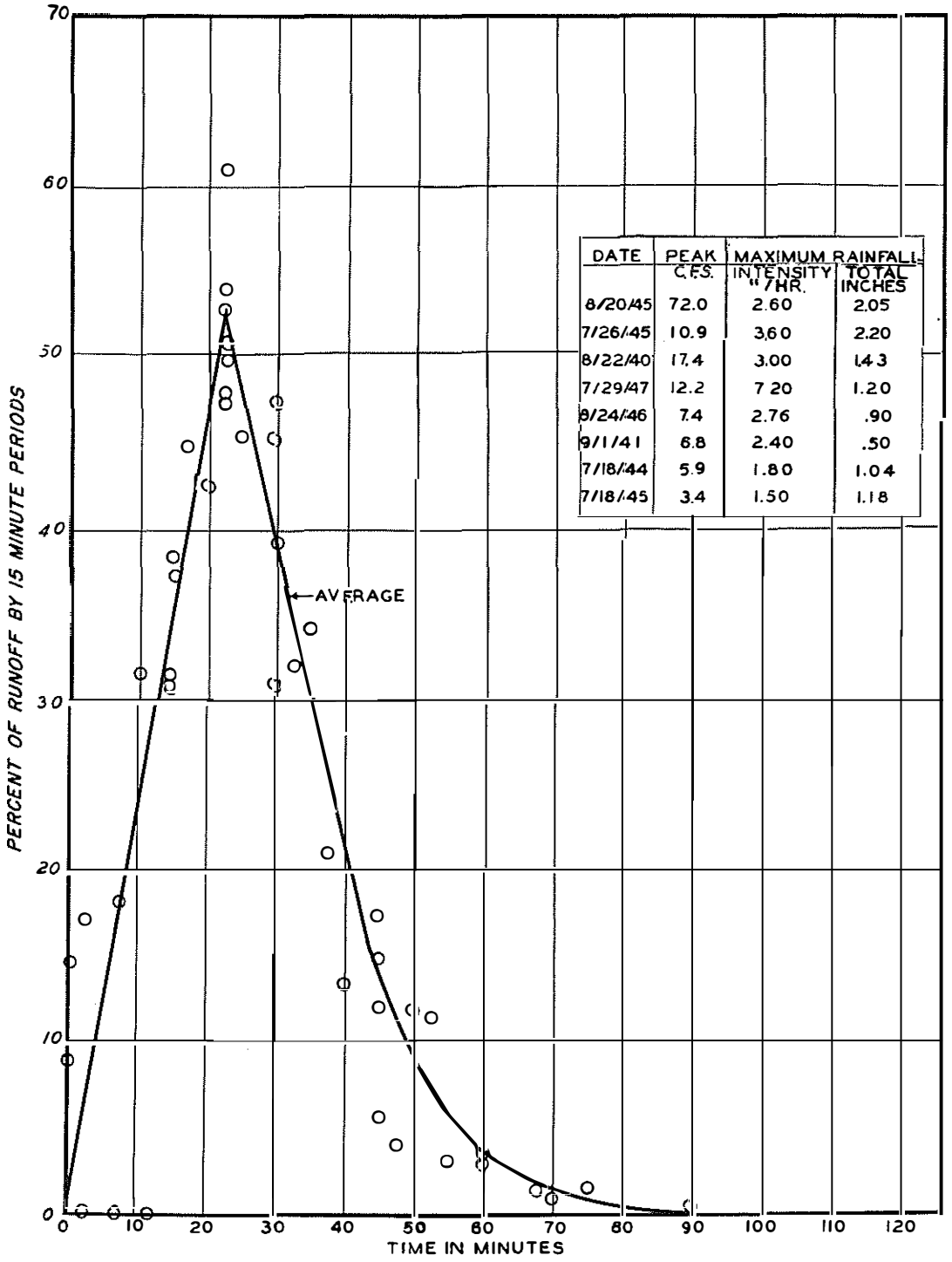

$X_3 - Y = 4.53 \text{Log} X_1 + .148 X_2 + .291 X_3 - 9.0$
Y = Snow In Forest (inches water content)
X_1 = Timber Volume (MBF/A - 4" dbh)
X_2 = Crown Density (percent)
X_3 = Snow In Open (inches water content)
n = 64 R = .90** $r_1 = .59$ $r_2 = .53$ $r_3 = .64$
Timber Volume - MBF/A
150
100
50
0
10
20
30
40
50
Crown Density - %
20" / 30"
5" / 10"
25" / 40"
10" / 20"
30" / 50"
15" / 30"
35" / 50"
15" / 20"
30" / 40"
10" / 10"
25" / 30"
40" / 50"
20" / 20"
35" / 35"
40" / 40"
Snow In Forest ÷ Snow In Open (Inches - Water Content On Apr. 1)

Figure 5.2(b) - Snow Storage in Forest and Open, Ida., Wyo., Utah, 1949-1952



DATE	PEAK C.F.S.	MAXIMUM RAINFALL INTENSITY "/HR.	TOTAL INCHES
8/20/45	72.0	2.60	2.05
7/26/45	10.9	3.60	2.20
8/22/40	17.4	3.00	1.43
7/29/47	12.2	7.20	1.20
8/24/46	7.4	2.76	.90
9/1/41	6.8	2.40	.50
7/18/44	5.9	1.80	1.04
7/18/45	3.4	1.50	1.18

Figure 5.3 - Hydrograph from Summer Storms
Missouri Gulch, Colorado - Manitou Experiment Forest
1940 - 1948, 4800 Acres

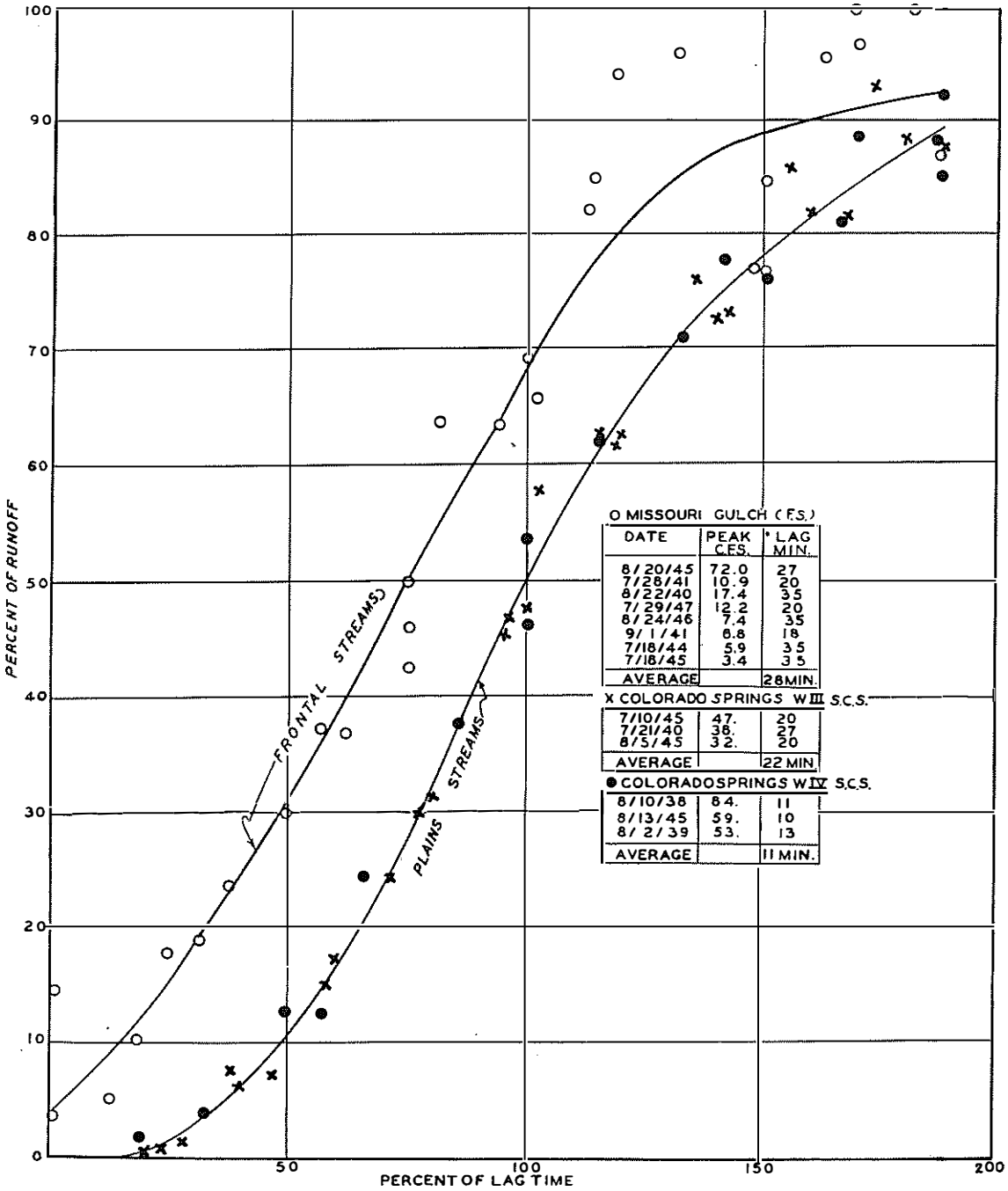

PERCENT OF RUNOFF
PERCENT OF LAG TIME
FRONTAL STREAMS
PLAINS STREAMS
O MISSOURI GULCH (F.S.)
DATE | PEAK C.F.S. | LAG MIN.
8/20/45 | 72.0 | 27
7/28/41 | 10.9 | 20
8/22/40 | 17.4 | 35
7/29/47 | 12.2 | 20
8/24/46 | 7.4 | 35
9/1/41 | 6.8 | 18
7/18/44 | 5.9 | 35
7/18/45 | 3.4 | 35
AVERAGE | | 28MIN.
X COLORADO SPRINGS W III S.C.S.
7/10/45 | 47. | 20
7/21/40 | 36. | 27
8/5/45 | 32. | 20
AVERAGE | | 22 MIN.
● COLORADOSPRINGS W IV S.C.S.
8/10/38 | 84. | 11
8/13/45 | 59. | 10
8/2/39 | 53. | 13
AVERAGE | | 11 MIN.

Figure 5.4 – Average Distribution Graphs
Small Watersheds Near South Platte River Watershed

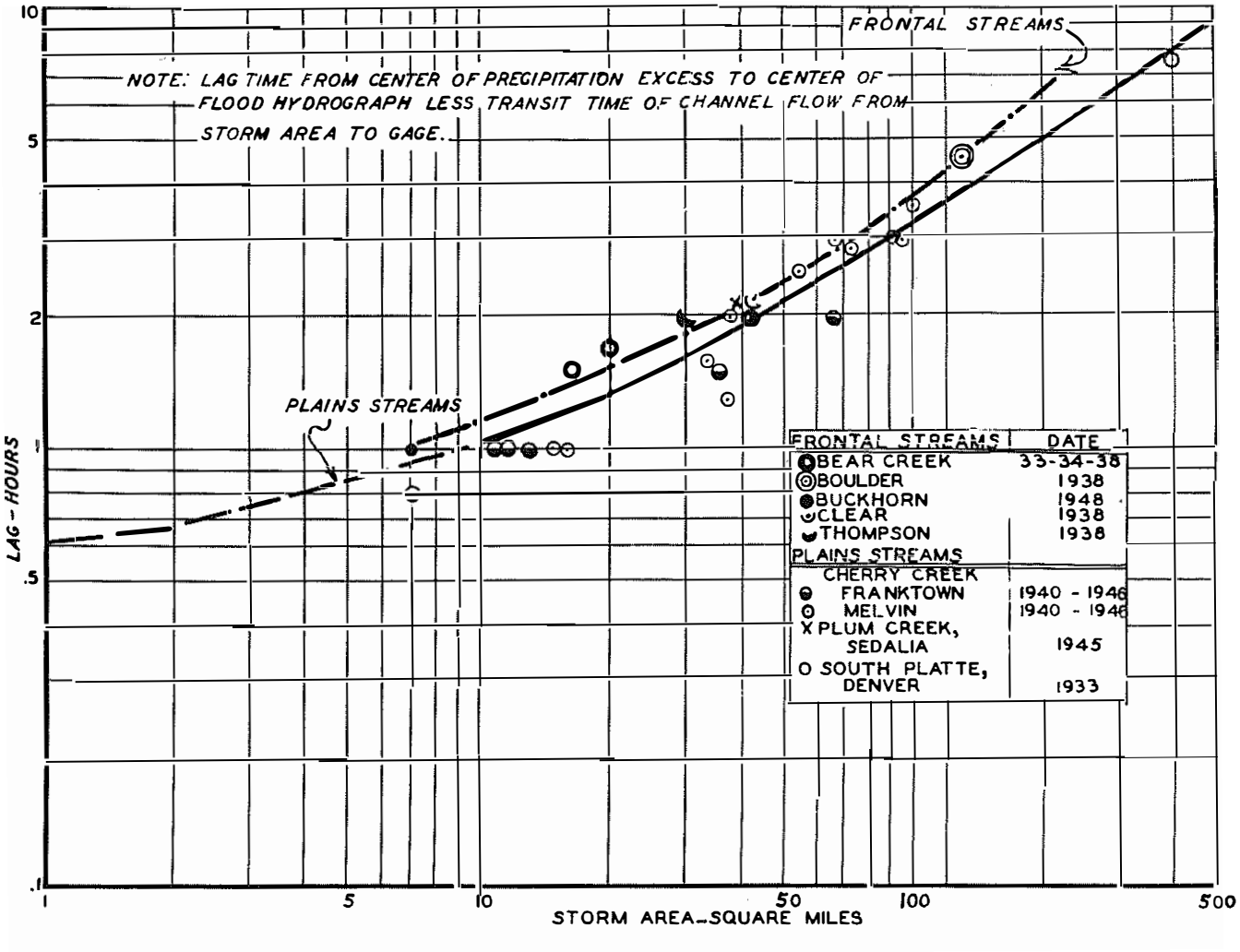


Figure 5.5 – Time-Lag VS. Storm Area
South Platte River Watershed

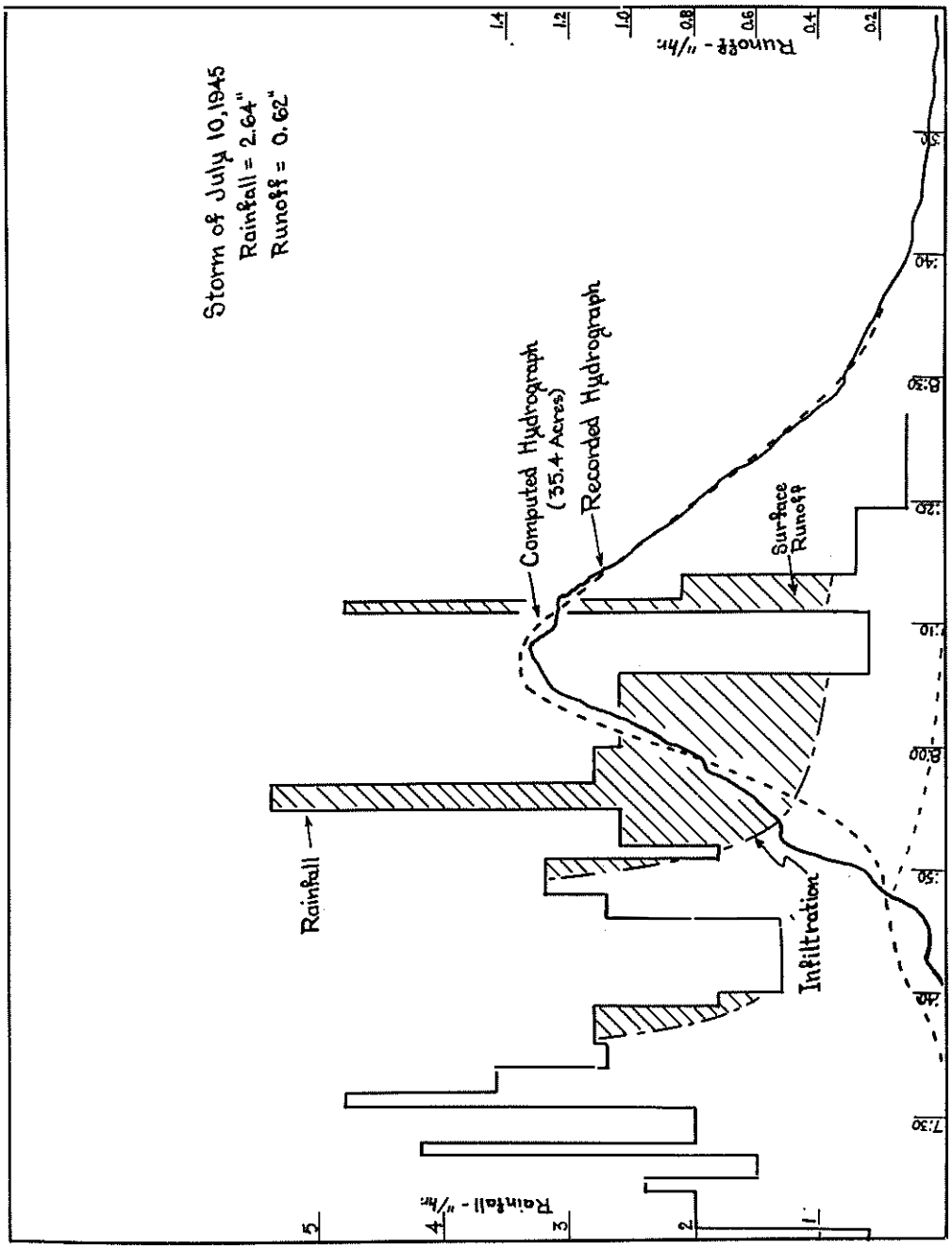


Figure 5.6 - Hydrograph from SCS Experimental Watershed W-111, Colorado.

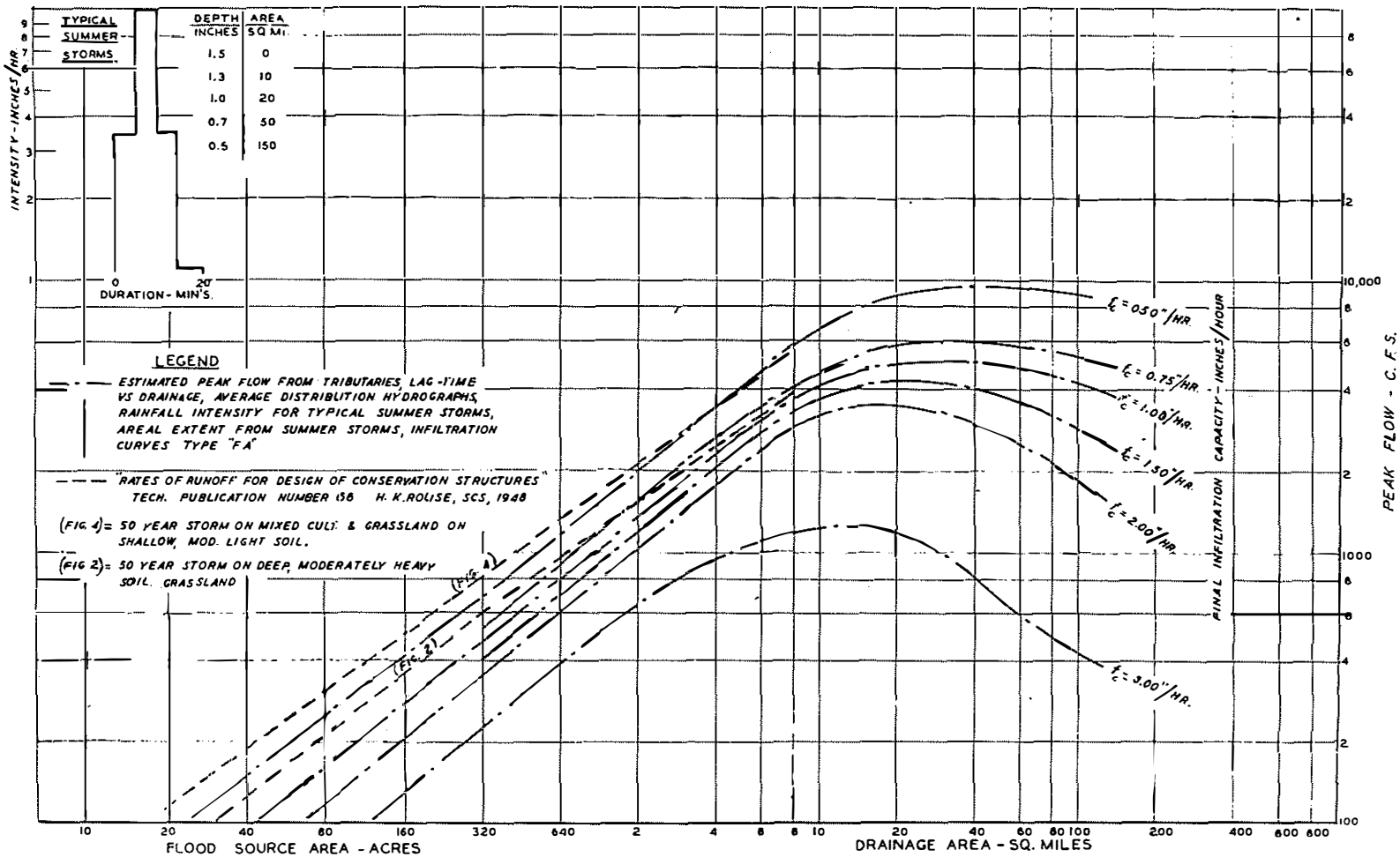

TYPICAL SUMMER STORMS
DEPTH INCHES
AREA SQ MI.
1.5 0
1.3 10
1.0 20
0.7 50
0.5 150
INTENSITY - INCHES/HR.
0
20
DURATION - MIN'S.
LEGEND
ESTIMATED PEAK FLOW FROM TRIBUTARIES, LAG-TIME VS DRAINAGE, AVERAGE DISTRIBUTION HYDROGRAPHS, RAINFALL INTENSITY FOR TYPICAL SUMMER STORMS, AREAL EXTENT FROM SUMMER STORMS, INFILTRATION CURVES TYPE "FA"
"RATES OF RUNOFF FOR DESIGN OF CONSERVATION STRUCTURES" TECH. PUBLICATION NUMBER 156 H. K. ROUSE, SCS, 1948
(FIG. 1) = 50 YEAR STORM ON MIXED CULT. & GRASSLAND ON SHALLOW, MOD. LIGHT SOIL.
(FIG 2) = 50 YEAR STORM ON DEEP, MODERATELY HEAVY SOIL. GRASSLAND
f_c = 0.50"/HR.
f_c = 0.75"/HR.
f_c = 1.00"/HR.
f_c = 1.50"/HR.
f_c = 2.00"/HR.
f_c = 3.00"/HR.
FINAL INFILTRATION CAPACITY - INCHES/HOUR
PEAK FLOW - C.F.S.
10,000
1000
100
10 20 40 60 160 320 640 2 4 8 8 10 20 40 60 80 100 200 400 600 800
FLOOD SOURCE AREA - ACRES
DRAINAGE AREA - SQ. MILES

Figure 5.7- Estimated Flood Peak From a 1.5 Inch Design Storm

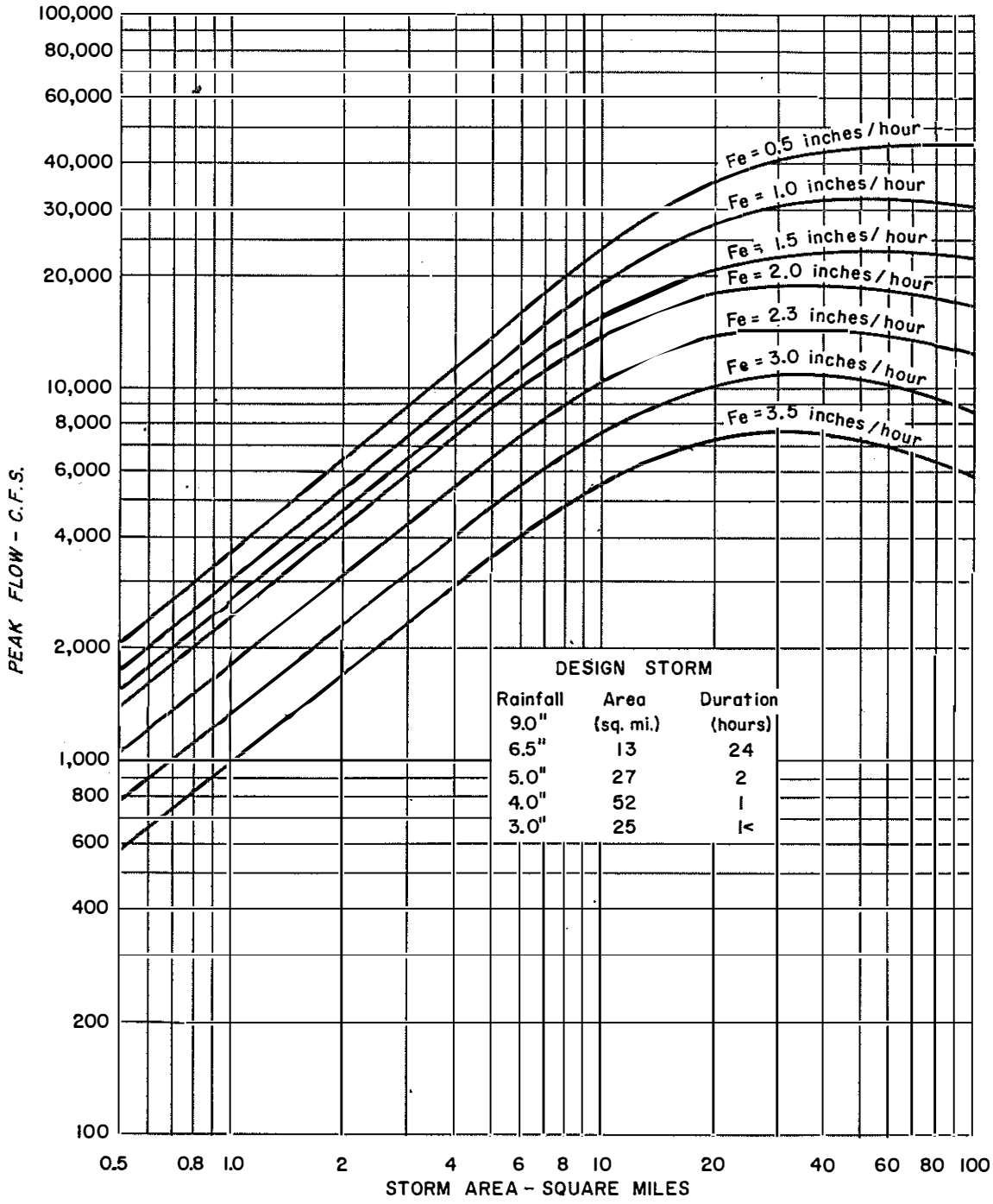


Figure 5.8 – Estimated Flood Peaks from a 9.0" Cloudburst

an actual infiltration curve can be established. For practical purposes, the areal infiltration curve and the one unit hydrograph can be found which will best reproduce a series of flood hydrographs. From previous infiltration tests on small plots on comparable sites, the typical shape of the areal infiltration curve is estimated--namely, that infiltration drops rapidly in the first 15 minutes and then levels off to approach a final capacity or subsoil percolation rate. This trial curve is then adjusted in time until computed surface runoff is equal to the measured, figure 5.6.

Examples of these computations are given below. Surface runoff depths computed by 5-minute periods across the top table have been distributed vertically by the percentage distribution graph shown on the left of the table. The total hydrograph for the small watershed is the summation of values horizontally tabulated at the right of the table.

		Computed Present Runoff								Total	
Time (Min.)		5	10	15	20	25	30	35	40	Inches	In/Hr.
Rainfall		.22	.11	.25	.19	.32	.24	.05	.18	2.64	
Infilt.		.17	.11	.23	.13	.09	.08	.08	.08		
Runoff		.05	0	.02	.06	.23	.16	0	.10	.62	
Time	%										
5	4.0	.002								.002	.02
10	18.5	.009	0							.009	.11
15	28.5	.014		.001						.015	.18
20	21.5	.012		.004	.002					.018	.21
25	13.0	.007		.006	.011	.009				.033	.39
30	7.5	.004		.004	.017	.043	.006			.074	.89
35	4.0	.002		.003	.013	.066	.030	0		.114	1.35
40	2.0	.001		.002	.008	.049	.046		.004	.110	1.31
45	1.0	.001		.001	.005	.030	.034		.018	.089	1.06
50					.002	.018	.021		.029	.070	.83
55					.001	.009	.012		.021	.043	.53
60					.001	.004	.006		.013	.024	.29
65						.002	.003		.008	.013	.15
70						.001	.001		.004	.006	.07
75									.002	.002	.03
80									.001	.001	.01

It may be desirable to utilize the relations previously derived in estimating peak flows for design purposes. A graphical presentation of peak flows involves many variables such as the area of the basin, the areal extent of the storm, the intensity pattern of the rainfall, timelag and unit hydrograph characteristics of the typical tributary, and infiltration capacity of the watershed depending on plant cover condition and soil types. These relations are shown on figures 5.7 and 5.8, illustrating a 1.5-inch typical summer storm and a 9-inch cloudburst.

The typical shape of the curves on figure 5.7 is due to the conical shape of the local storm. This indicates that the peak flow within a large cloudburst flood might be reasonably uniform from about 10 to 100 square miles. At the higher limits channel storage, debris deposition, and other losses would tend to reduce the upstream peak even more than shown by these curves. In support of the design floods shown on figure 5.8 are the observed floods from mountain and foothill tributaries estimated to peak at several hundred to about a thousand second-feet per square mile. Experimental watersheds operated by the Soil Conservation Service for a few years verify figure 5.7 for small areas.

It is intended that larger cloudbursts be used for spillway capacity and other structural design for maximum local summer floods. Smaller summer storms can be used to design minor structural measures and vegetative treatments to withstand the maximum recorded short-time rainfalls. Larger floods, from drainage basins over about 100 square miles, from general spring storms involving melting snow would be more severe for larger mountain tributaries.

5.3 - Flood Prevention Measures. Management practices and land treatment as listed below provide both watershed protection and flood prevention. Table 5.2 is an example of how measures might be classified for flood prevention, water yield, erosion control, or watershed protection. For comparison, channel improvements and downstream structures are also rated.

Measures for treatment of slopes have different effects upon hydrologic processes such as: interception, detention, evapo-transpiration, soil-water storage, etc. Table 5.3 is an example of some research which developed equations for these processes. Examples are shown for different amounts of precipitation. Subtotals are given in percent effectiveness as a tentative rating for flood prevention, water yield, etc. References are given to the sources of this data.

Examples of Watershed Protection or Flood Prevention Measures

1. Slope Treatment

   Vegetative measures

      Seeding (erosion sources, emergency, trenches)
      Planting (trenches, slides, road cuts)
      Sodding (road ditches, waterways, terraces)
      Cover manipulation (stripcut, aspen, brush)

   Soil treatment measures

      Mulching (seeding, road fills, abandoned roads)
      Ground preparation (scarify, cultivate)

Runoff retardation (trenches, pitting, road drainage)
Soil amendment (fertilizer, conditioners)

Supplementary measures

Erosion control (wattling, brush fences)
Slide stabilization (walls, cribs, drains)
Wind control (snow fence)

Biological measures

Pest control (insects, rodents)

Management practices

Fire control
Timber (snow control strips)
Range (fence seeding)
Recreation
Engineering

2. Gully Treatment

Vegetative measures

Seeding (gully banks)

Soil reclamation and restoration (mulching, ground preparation)

Structural measures

Gully-head control (diversion, drops)
Water and sediment control (drops, sills, plugs, dams)

Management practices

Clearing obstructions
Control of use
Other

3. Channel Treatment

Vegetal measures

Seeding
Planting
Cover manipulation

Soil treatment measures

- Mulching
- Erosion
- Water control
- Soil amendment

Structural measures

- Channel bed stabilization
- Bank protection
- Water and sediment storage

Biological measures

- Pest control
- Beaver planting or removal

Management practices

- Control use
- Cleanup

Table 5.2--Example of Relative Effect of Measures

	Flood Prevention			Water	Erosion	Watershed
	Overland	Subsurface	Snowmelt	Yield	Sediment	Protection
FOREST MANAGEMENT						
Tree planting	High	Medium	High	Poor	Good	Good
Shrub planting	High	Low	Slight	Poor	Good	Good
Insect & disease	Slight	.....	.....	.....	.....	Good
Rodent control	Slight	.....	.....	.....	.....	Good
Grazing control	High	Slight	Slight	Slight	Good	Good
Fire control	High	Low	High	Slight	Good	Good
RANGE MANAGEMENT						
Grass seeding	High	Low	None	Slight	Good	Good
Rodent control	Slight	.....	.....	.....	.....	Good
Poisonous plants	Slight	.....	.....	.....	.....	Good
Driveways	Indirect	None	None	None	Good	Good
Fences, etc.	Indirect					Good
Water development	Indirect					Good
SLOPE AND GULLY TREATMENT						
Roadsode erosion	Low	None	Low	Slight	Good	
Reseeding grass & woody	High	Low	None	Slight	Good	
Contour trenches	High	None	None	Poor	Good	
Logging and trail stabilization	Low	None	Low	Slight	Good	
Slide stabilization	None	None	None	None	Good	
Sheet and gully stabilization	High	None	None	Slight	Good	
CHANNEL IMPROVEMENT						
Stream bank	High	High	High	None	Good	
Channel capacity	High	High	High	None	Good	
Subwaterway	High	High	High	None	Good	
Diversions and dikes	High	High	High	None	Good	
Floodways	High	High	High	None	Good	
Flood detention	High	Medium	Low	Good	Good	
Debris basins	Low	None	None	None	Good	
Sediment stabilization	Slight	None	None	None	Good	
Water spreading	High	Low	Low	Poor	Good	

Table 5.3[1]--Effect of Slope Treatment on Hydrologic Processes (Example)

Measures	Type	Interception		Detention	Initial Loss		Soil Storage		Evapo-transpiration
		Rain (2"-10")	Snow (5"-10")	Surface	(Subtotal) Surface	(Subtotal) Channel	Detention	Retention	
Vegetative Seeding	Bare soil	-	-		.5-1.5"		1-2"/ft.	2-4"/ft.	.10"/day
	Grass	.17 .85	-						
	Brush	.21 .70	.16 .30			.3-4"/day			
	Oak	.41 -					Humus .2D	Humus .4D	
Planting	Pine	.23 .71	.40 .70						
Flood Prevention		P 5-20%	P 3-10%	Q 5-10%	F 20-30%	Q 5-60%	C 0-15%	C 0-15%	
Soil Treatment	Pitting			0.3"					
	Furrows			0.5"					
	Trenches			1.5"+					
Flood Prevention				(1-2" Storm) Q 20-100%					
Management Timber	Cutting		(10"-40") 2.0 16.0						12-17"/yr.
	Brush burn								2-3"/yr.
	Aspen cut								
Range	Reseeding								1-4"/yr.
Water Yield			CP 20-40%			Riparian 0-100%			CP 15-30%

References

Grass I = .005h+ .08hP
Oak I = .05 + .18P (Horton)
Brush I = .08 + .06P (Rowe)
Pine I = .11 + .06P (Rowe)
L. Pine I = .20CP (Wilm)
P. Pine I = .36CP (Ingebo)
Spruce I = .40CP (Ingebo)
Spr.-fir I = .39CP (Rosa)
Bare S = .007Q^1.33 + NQ^.33 (Izzard)
Grass S = .018 Q^1.14 (Rosa)
Sage S = .015 Q^1.10 (Rosa)
Brush S = .013 Q^1.10 (Rosa)

Range S = 0.3 (Fav.-Fc) (Rosa)
Pasture S = CQ (good) (SCS)
Bare soil S = .17Q (poor) (SCS)

Channels L = 0.2X(Q).5 / (V)
X = 0.4 clay
0.7 loam (Moritz)
1.7 sandy
2.2 gravelly

ET = .00015 (°F-32) + 0.9 (Lowry-Johnson)

I = interception (in.)
h = height of grass (ft.)
P = storm rainfall (in.)

S = detention (in.)
Q = overland (in./hr.)
N = roughness (coeff.)

C = cover density (%)
H = humus depth (in.)
D = soil depth (in.)

5.4 - Effect of Cover and Soil on Runoff

5.41 - Watershed Studies. A watershed is studied in four steps:

1. A field survey of soil-cover complexes to delineate acreages.

2. A field and laboratory study of soil samples to determine storage and percolation.

3. A hydrologic computation to route the water through the soil profile.

4. A hydrologic analysis using future watershed conditions to evaluate cover and soil improvement. Such an analysis involves the following considerations and procedures.

a. Soil-cover complexes are subdivisions of the watershed which have fairly uniform infiltration and storage characteristics. The soil characteristics used are the combinations of depth, texture, and internal drainage which determine differences in percolation, storage, and infiltration capacity. Hydrologic condition of forest and woodland cover types is based on average humus depths as related to stand size classes and the degree of stocking. Open land is classified by farming practices and pasture or range conditions are determined by ground-cover density.

b. The total amount of infiltrated water depends on the percolation rate, transmission velocity, and retention or detention storage for each horizon of the soil profile. The relative values for the above are determined from undisturbed soil samples. An adjustment is made to actual field conditions.

c. The soil water-percolation indices for a soil-cover complex are the average rates which, when applied to an actual storm rainfall pattern, will yield a volume of runoff equal to that observed at a stream gage on the watershed. Trial computations are required to route the actual storm rainfall through the soil horizons of each soil-cover complex to determine the overland flow and total infiltrated water which will reproduce the actual hydrograph.

d. The final indices are then applied to the future acreages of each soil-cover complex and the volumes of runoff again determined. Hydrographs of future streamflow from both overland and subsurface flow are constructed for comparison with present hydrographs as a measure of the effect of improvement in cover and soil factors.

5.42 - Soil Properties

Retention and Detention Storage. Retention storage is the amount of water the soil can hold against the pull of gravity. Detention storage is the difference between saturation and retention storage.

The retention storage space that is available at any time depends on previous rainfall and evapo-transpiration. Water in retention storage is held in the smaller pore spaces and as a closely adhering film on the soil particles. Any deficiency in retention storage is satisfied first as the wet front moves downward. Detention storage consists of the larger pore spaces through which water moves at the pull of gravity. Percolation rates and transmission velocities depend on the size, character, continuity, and amount of detention pore space.

Percolation Rate. Percolation rates of saturated soil samples are measured in the laboratory. Since evidently these rates are higher than those that occur in the natural soil profile, these rates may be reduced by trial-and-error methods until a factor will give a volume of surface runoff for the recorded storm on the watershed as estimated from the flood hydrograph.

Transmission Velocity. Transmission velocity is the speed in inches per hour of the wet front as it moves down through the soil. The maximum velocity can be computed from the fundamental flow equation $Q = AV$, in which Q is the percolation rate. A is the percentage of pore space in detention storage, and V is the transmission velocity.

When the supply of water equals or exceeds the percolation rate and detention storage and percolation rate remain constant with an increase in depth, the transmission velocity of the wet front is constant. Any change in either detention storage or percolation rate as the wet front moves to a lower soil horizon, however, will be reflected in the transmission velocity.

When the rate of supply is less than the percolation rate, the transmission velocity varies directly as the rate of supply. In computations the time of transmission through each horizon is used; it is equal to the depth of the horizon divided by the transmission velocity.

Subsurface Runoff. Subsurface runoff is considered on a watershed basis only and not by separate soil-cover complexes. Lateral drainage of the soil profile by subsurface flow makes it possible for additional water to be infiltrated into the soil profile. The effect of subsurface flow can be compensated for by increasing the percolation rates by the rate of contribution to lateral flow. This compensation is included in the factor for modifying percolation rates to agree with the flood hydrograph analysis.

Example of Soil Cover Effects During a General Storm[1]

Soil properties of this example are shown in the following table

Soil Horizon	Retention storage (inches)	Detention storage (inches)	Percolation rate (inches/hr.)	Time of transmission (hours)
GRAZED WOODLAND WITH MULL HUMUS AND MEDIUM-TEXTURED, IMPERFECTLY DRAINED SOILS				
Surface	--	0.100	--	--
Humus	0.870	.378	15.10	0.023
Lower A	1.404	.740	6.50	.103
Upper B	1.490	.754	2.40	.305
Lower B	1.630	.426	1.40	.298
C	--	--	.30	--
GOOD PASTURE ON MEDIUM-TEXTURED IMPERFECTLY DRAINED SOILS				
Surface detention	--	0.100	--	--
AB	2.457	.627	9.20	.065
Upper B	2.432	.496	2.20	.219
Lower B	--	--	.30	--
C	--	--	.30	--
UNGRAZED FOREST-MOR HUMUS DEPTH OF 3.11 INCHES ON MEDIUM-TEXTURED, IMPERFECTLY DRAINED SOILS				
Surface detention	--	0.200	--	--
Humus	1.176	1.052	118.00	.006
Lower A	1.987	.800	8.50	.085
Upper B	2.577	.754	2.40	.310
Lower B	2.684	.427	1.40	.248
C	--	--	.30	--

[1] Whelan, D. E., Northeast Forest Experiment Station, 1954

Table 5.4--Computations Used in 'Routing' Infiltrated Water Through the Soil To Determine Surface Runoff

(For Grazed Woodland With Mull Humus and Medium-Texture, Imperfectly Drained Soil)

RAINFALL			INFILTRATION						
			Surface			Humus			Lower A
Time increment	Rainfall intensity	Amount of rainfall	Inflow	Storage	Outflow	Accumulated time	Storage	Outflow	Accumulated time
Hours	Inches	Inches	Inches	Inches	Inches	Hours	Inches	Inches	Hours
0.167	4.63	0.772	0.772	—	0.772	0.167	0.106	0.666	0.144
.167	2.32	.387	.387	—	.387	—	.053	.440	--
.500	.91	.450	.450	--	.450	—	.021	.482	—
.167	.31	.052	.052	—	.052	—	.007	.066	—
.167	.23	.039	.039	—	.039	—	.005	.041	--
.083	1.69	.142	.142	--	.142	--	.039	.108	--
.583	.27	.154	.154	—	.154	--	.006	.187	—
.333	0	0	—	--	--	—	—	.006	--
.167	1.01	.167	.167	--	.167	—	.023	.144	--
.417	.06	.026	.026	--	.026	--	.001	.048	--
.250	.52	.129	.129	—	.129	--	.012	.118	—
.083	1.54	.129	.129	--	.129	—	.035	.106	—
.083	3.60	.296	.296	--	.296	—	.092	.239	--
.167	.47	.078	.078	—	.078	—	.120	.050	--
.333	.17	.013	.013	—	.013	—	.033	.100	--
.167	1.54	.257	.257	—	.257	—	.240	.050	--
.167	8.26	1.375	.288	.100	.188	--	.378	.050	—
.167	0	0	—	.050	.050	—	.378	.050	—
.033	12.75	.426	.060	.100	.010	—	.378	.010	—
.216	1.25	.270	.065	.100	.065	—	.378	.065	—
.250	1.75	.438	.075	.100	.075	--	.378	.075	—
.333	.04	.013	.013	.013	.100	—	.378	.100	—
.250	.05	.013	.013	—	.026	—	.329	.075	—
.083	.47	.039	.039	--	.039	—	.343	.025	--
1.667	0	0	—	—	—	--	—	.343	—
1.000	.05	.052	.052	—	.052	—	.001	.051	—
1.000	0	0	--	—	—	—	—	.001	—
1.000	.01	.013	.013	--	.013	—	—	.013	--
1.000	.04	.039	.039	—	.039	—	.001	.038	—
.333	.08	.026	.026	--	.026	—	.002	.025	—
.250	.52	.129	.129	--	.129	—	.012	.119	--
.167	1.54	.257	.257	--	.257	—	.035	.234	--
.083	3.09	.257	.257	--	.257	—	.071	.221	--
.167	.78	.129	.129	--	.129	—	.018	.182	--
.500	.10	.052	.052	--	.052	—	.002	.068	—
.167	2.00	.335	.335	--	.335	—	.046	.291	—
.167	.62	.103	.103	—	.103	--	.014	.135	--
.167	3.87	.643	.643	—	.643	—	.089	.568	—
.250	2.16	.541	.475	.100	.375	—	.378	.086	--
.167	0	0	—	.050	.050	—	.378	.050	--
.083	2.78	.232	.075	.100	.025	—	.378	.025	--
.083	.31	.026	.025	.100	.025	—	.378	.025	—
1.333	0	0	—	--	.100	—	.078	.400	—
.083	.31	.026	.026	--	.026	--	.079	.025	--
16.000	0	0	—	—	--	—	--	.079	--
1.000	.01	.013	.013	—	.013	1.000	—	.013	.977
1.000	.01	.013	.013	--	.013	--	—	.013	--
1.000	.01	.013	.013	--	.013	--	—	.013	--
1.000	.01	.013	.013	--	.013	--	—	.013	--
10.083	0	0	--	—	—	—	—	--	--
.083	.31	.026	.026	--	.026	—	.007	.019	.060
1.583	0	0	--	—	--	--	—	.007	—
.250	.62	.154	.154	—	.154	.250	.014	.140	.227
.417	.05	.026	.026	--	.026	—	.001	.039	--
.083.	1.24	.103	.103	—	.103	—	.029	.074	.060
57.167	—	8.886	--	—	--	--	—	--	—

Table 5.4. --Continued

INFILTRATION (continued)										RUNOFF
Lower A		Upper B			Lower B			C	Total rainfall infiltrated	
Storage	Outflow	Accumulated time	Storage	Outflow	Accumulated time	Storage	Outflow	Storage		
Inches	Inches	Hours	Inches	Inches	Hours	Inches	Inches	Inches	Inches	Inches
0.568	0.098	0.041	0.098	—	--	--	--	0.585	0.772	—
.607	.410	.208	.499	—	--	--	--	.585	1.159	--
.377	.712	.708	.754	0.457	0.403	0.426	0.031	.616	1.609	--
.393	.050	--	.754	.050	--	.426	.050	.666	1.661	--
.384	.050	--	.754	.050	--	.426	.050	.716	1.700	--
.467	.025	--	.754	.025	—	.426	.025	.741	1.842	--
.479	.175	--	.754	.175	--	.426	.175	.916	1.996	--
.385	.100	--	.754	.100	--	.426	.100	1.016	1.996	--
.479	.050	--	.754	.050	--	.426	.050	1.066	2.163	—
.402	.125	--	.754	.125	--	.426	.125	1.191	2.189	--
.445	.075	--	.754	.075	--	.426	.075	1.266	2.318	--
.526	.025	--	.754	.025	—	.426	.025	1.291	2.447	--
.740	.025	--	.754	.025	--	.426	.025	1.316	2.743	--
.740	.050	—	.754	.050	--	.426	.050	1.366	2.821	--
.740	.100	--	.754	.100	--	.426	.100	1.466	2.834	--
.740	.050	--	.754	.050	--	.426	.050	1.516	3.091	--
.740	.050	--	.754	.050	--	.426	.050	1.566	3.379	1.087
.740	.050	--	.754	.050	--	.426	.050	1.616	3.379	—
.740	.010	--	.754	.010	--	.426	.010	1.626	3.439	.366
.740	.065	--	.754	.065	--	.426	.065	1.691	3.504	.205
.740	.075	--	.754	.075	--	.426	.075	1.766	3.579	.363
.740	.100	--	.754	.100	--	.426	.100	1.866	3.592	--
.740	.075	--	.754	.075	--	.426	.075	1.941	3.605	--
.740	.025	--	.754	.025	--	.426	.025	1.966	3.644	--
.583	.500	—	.754	.500	--	.426	.500	2.466	3.644	--
.334	.300	--	.754	.300	--	.426	.300	2.766	3.696	--
.035	.300	--	.754	.300	--	.426	.300	3.066	3.696	--
.001	.047	--	.501	.300	--	.426	.300	3.366	3.709	--
.004	.035	--	.236	.300	--	.426	.300	3.666	3.748	--
.008	.021	--	.157	.100	—	.426	.100	3.766	3.774	--
.054	.073	--	.155	.075	--	.426	.075	3.841	3.903	--
.157	.131	--	.236	.050	--	.426	.050	3.891	4.160	--
.249	.129	--	.340	.025	--	.426	.025	3.916	4.417	--
.080	.351	--	.641	.050	--	.426	.050	3.966	4.546	--
.010	.138	--	.629	.150	--	.426	.150	4.116	4.598	--
.206	.095	--	.674	.050	--	.426	.050	4.166	4.933	--
.211	.130	--	.754	.050	--	.426	.050	4.216	5.036	--
.729	.050	—	.754	.050	--	.426	.050	4.266	5.679	--
.740	.075	--	.754	.075	--	.426	.075	4.341	6.154	.066
.740	.050	—	.754	.050	--	.426	.050	4.391	6.154	--
.740	.025	--	.754	.025	--	.426	.025	4.416	6.229	.157
.740	.025	--	.754	.025	--	.426	.025	4.441	6.254	.001
.740	.400	--	.754	.400	--	.426	.400	4.841	6.254	--
.740	.025	--	.754	.025	--	.426	.025	4.866	6.280	--
--	.819	--	--	1.573	--	--	1.999	6.865	6.280	--
.002	.011	.874	.004	.007	5.69	.003	.004	6.869	6.293	--
.002	.013	--	.004	.013	--	.003	.013	6.882	6.306	--
.002	.013	--	.004	.013	--	.003	.013	6.895	6.319	--
.002	.013	--	.004	.013	--	.003	.013	6.908	6.332	--
—	.002	--	--	.006	--	--	.009	6.917	6.332	--
.019	--	--	--	--	--	--	--	6.917	6.358	—
--	.026	--	--	.026	--	--	.026	6.943	6.358	—
.064	.076	.124	.076	—	--	--	--	6.943	6.512	--
.005	.098	.541	.028	.146	.236	.146	--	6.943	6.538	--
.075	.004	--	.022	.010	.319	.150	.006	6.949	6.641	--
--	--	--	--	--	—	--	--	--	6.705	2.245

Procedure. The infiltrated water is traced through the soil by carefully accounting for the time stages in the movement of the wet front and the changes in water storage in each soil horizon. The computations are facilitated by considering detention storage, percolation rate, and time of transmission to have uniform values throughout each soil horizon.

5.43 - Example of Soil-Cover Effects During General Storms

Computation of Soil Storage and Runoff. The first line of table 5.4 shows that during the first period of uniform rainfall intensity (0.167 hour), 0.772 inches of rain fell at an intensity of 4.63 inches per hour. Since this intensity was less than the percolation rates of the humus (15.10) and the lower A horizon (6.50), this rain was infiltrated into those upper horizons as fast as it fell. But the upper B horizon had a percolation rate of only 2.40; so the water could infiltrate into this horizon no faster than the percolation rate.

At the end of this time increment, the humus had stored 0.106 inches of water. This was calculated as transmission time of the soil horizon (0.023 hour) times the rainfall intensity. The rest of the rainfall for this period flowed down into the lower A horizon.

Water flowed into the lower A horizon for a period of 0.144 hour. This was calculated as rainfall period (0.167) minus transmission time in the humus (0.023). Water flowed out of the lower A horizon for 0.041 hour--0.144 minus the horizon's transmission time, 0.103.

Since the percolation rate of the upper B horizon was less than the rainfall intensity, this percolation rate controlled the inflow to the upper B horizon. The percolation rate (2.40) times the length of time water flowed into the horizon (0.041) gave the amount of water that infiltrated into this horizon: 0.098 inch. All of this water was stored in this horizon.

The storage in the lower A horizon was computed as the difference between inflow (0.666) and outflow (0.098), or 0.568 inch.

This procedure was carried out for each period of uniform rainfall intensity during the storm. As the amount of rainfall increased and the soil horizons became saturated, the percolation rates determined the speed at which the water infiltrated through the various horizons.

The amount of surface runoff was computed simply by subtracting the amount of water infiltrated from the total rainfall. In this example, of 8.886 inches of rain 2.245 inches were surface runoff.

Graphic Story of Storm. The routing procedure used in this example is shown graphically in figure 5.9. The uppermost graph in this figure shows amounts of rainfall by successive periods of uniform

intensity. The unshaded portions of the bars show infiltrated water, the shaded portions surface runoff. The graphs below show the relationship of storage to storm duration for each soil horizon.

During the first part of the storm the soil was able to absorb 3.4 inches of rainfall in 3 hours and 40 minutes without any surface runoff occurring. However, at the end of this period the lower A and the B horizons were saturated and could transmit water only at the percolation rate of the C horizon.

The next two bursts of rain, lasting 20 minutes, completely utilized the remaining storage space in the humus horizon and surface detention, and more than 1 inch of runoff resulted. Since the humus could then absorb water only at the percolation rate of the C horizon, 1.1 inches of rainfall in the next 40 minutes resulted in about 0.9 inch of surface runoff.

During the next 8 hours a large part of the water temporarily stored in the humus, lower A, and well-drained B horizons drained into the C horizons. Then several additional bursts of rain caused these horizons to become saturated again and resulted in about 0.2 inch of surface runoff.

For any given storm and its antecedent conditions, there is a definite limit to the total amount of water that can infiltrate into a soil. The maximum limit for a given storm occurs when the humus, lower A, and B horizons are saturated for the duration of the storm and supply water to the C horizon at a constant rate. This condition seldom occurs, because intervals of little or no rainfall generally cause a slackening in the supply of water. These slack periods give the humus and lower A horizons time to drain.

The recovery of detention storage space is the upper soil horizons--as this example--enables the soil to absorb a series of rainfall bursts (3). Thus the aggregate gain in infiltrated water is far more than the detention storage capacities of the humus and lower A horizons.

Summary. During a survey of the Allegheny River watershed, a large number of such "routings" were made for several soil-cover complexes. The results of these "routing" studies are shown in figure 5.10.

The upper graph shows how the amount of infiltrated water increased as the total storm rainfall increased. The lower graph shows the relationship between surface runoff and total rainfall.

These graphs indicate how deep humus and the practice of growing crops on the contour serve to increase infiltration and thus reduce the amount of flood runoff.

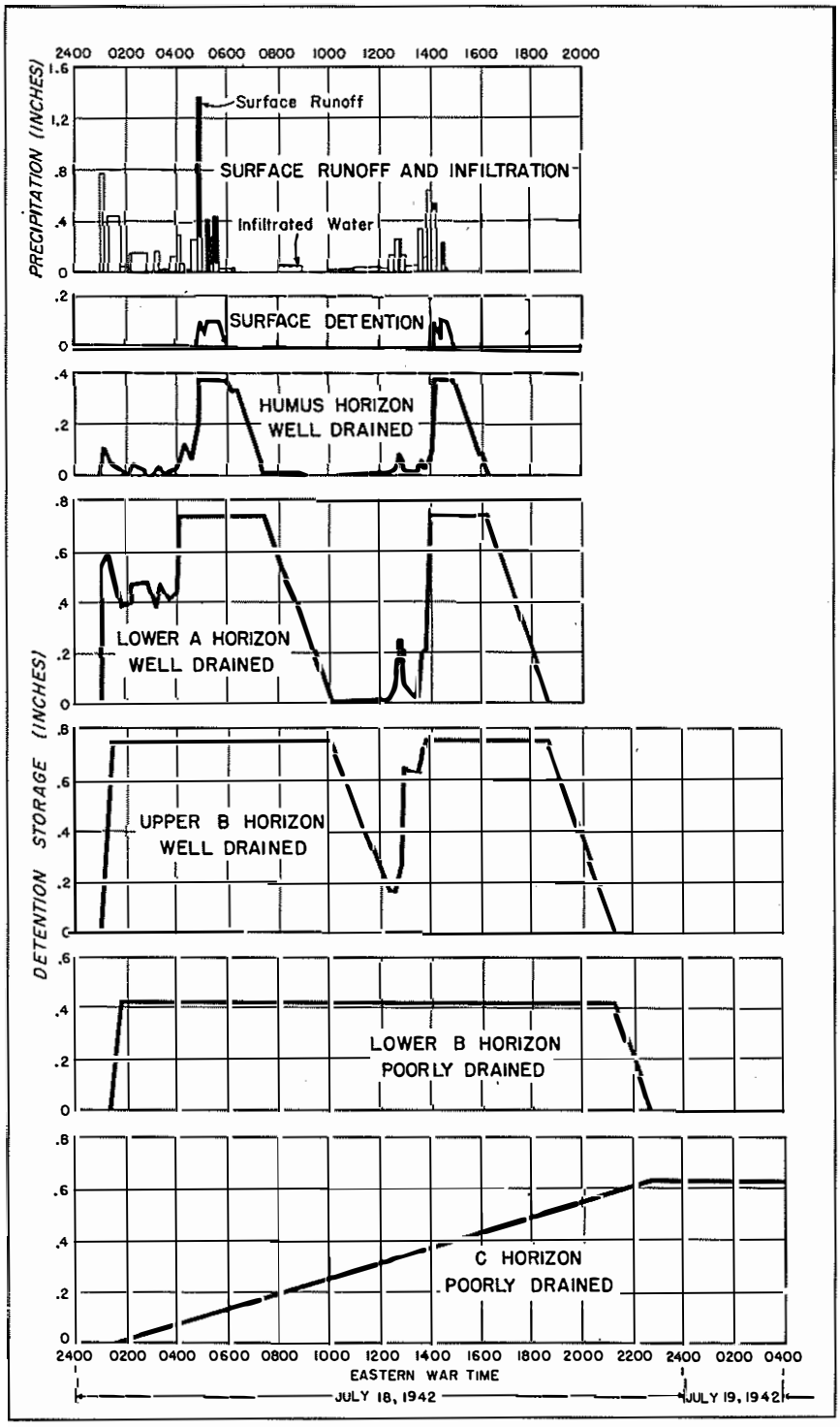


Figure 5.9 – Sample 'routing' of infiltrated water through the soil horizons of a grazed forest with mull humus and medium-texture imperfectly drained soil

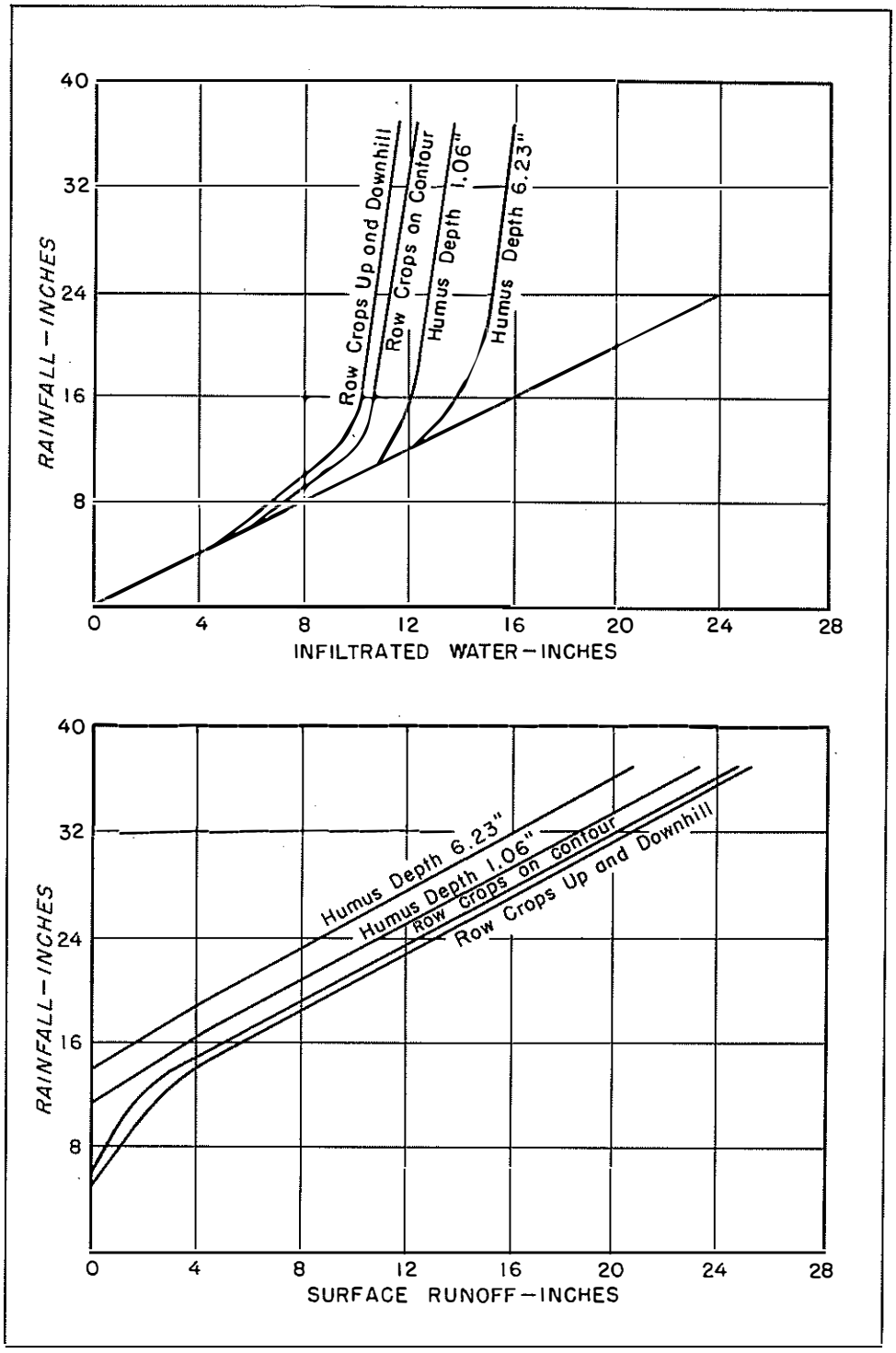


Figure 5.10 – Summary of 'routing' studies in the Allegheny River watershed, showing how deep humus and contour cropping help to reduce surface runoff

There are several advantages in this method for computing surface runoff. Consideration is given not only to the total storage of water in the soil, but also to all periods of total or partial recovery of storage space. Any retention storage space available because of evapotranspiration is easily taken into account during the routing procedure.

This method is applicable for evaluating a land-use program. Effects of contour tillage and improvement in vegetal cover can be evaluated in terms of increased surface detention storage. Effects of increase in humus depth can be evaluated in terms of greater storage and infiltration recovery.

With this method the amount of water infiltrated into the soil can be computed for any storm and any distribution of its rainfall intensities. The infiltration capacity of any soil can be determined from the retention and detention storage values, percolation rates, and transmission velocities of the different soil horizons. The infiltration capacity of the soil profile can also be determined at any time during the storm.

5.44 - Example of Soil-Cover Effects During Local Storms. The volume of overland flow from local storms is reduced by either increasing infiltration rates or increasing surface storage. Another effect is in causing a timelag by reducing the velocity of flow or converting surface flow to subsurface flow.

In a unit hydrograph the peak flow varies directly with the volume of runoff; therefore flood peaks are reduced in proportion to volume and damages reduced even greater. For local storms of short duration, the evaluation or the effectiveness of land treatment can be limited to the simple computation of runoff volumes, present and future.

1. Effects of Vegetative Measures. Natural and artificial revegetation are considered together since their effects differ only in time for effectiveness. They both increase plant cover density and infiltration rates and decrease erosion, with consequent decrease in flood peaks and sedimentation rates. The effects of revegetation on groundcover densities are estimated in the field by national forest personnel with assistance from regional office personnel when needed.

Improvement in total cover begins with improved management and is evaluated as continuing at a constant rate until the maximum improvement is reached. The densities at this maximum point are maintained indefinitely. Improvement in plant cover densities begins immediately after initiation of reseeding and increases rapidly for 3-5 years. Thereafter the rate of increase is the same as natural revegetation until a maximum is reached within the 50-year period of evaluation. If no remedial program is initiated on depleted sites, it is assumed that the densities will decrease at a constantly declining rate for 50 years and then remain indefinitely constant at this minimum point.

Increased ground cover densities result in increased infiltration rates. The amount of increase is determined from infiltration tests adjusted to watershed rates. Increased cover densities and consequent increased infiltration rates result in decreased run-off from the soil-cover complexes of a watershed.

The effects of the vegetative measures on erosion-source areas is estimated in the field by watershed-management personnel. Changes in erosion-source areas are used to determine changes in relative erosion rates with and without the recommended improvements. Relative erosion values are used in determining the effect of the improvements on sedimentation rates. They are determined for a given drainage area by multiplying the areas in the given erosion-source conditions by their respective relative erosion rates.

b. Effects of Soil Treatment Measures. This section describes a procedure for evaluating the effects of the small mechanical structures. The effects of contour trenches and furrows on flood peaks, for evaluation purposes, are considered to begin immediately upon installation. Their effects on sedimentation are considered in estimates of future erosion rates.

Contour trenches are, in effect, small storage reservoirs on the watershed slope. Their storage capacity is about 1.5 inches over the area treated. This is their maximum effectiveness. The amount which they store for any particular storm depends on the runoff available after infiltration is satisfied. This runoff seldom equals and never exceeds the capacity of the trenches for the storm patterns used in the evaluation. Since infiltration rates increase as cover densities increase, the maximum effectiveness of the trenched area may be immediately after installation or later when vegetation has improved. The amount of surface detention for each storm pattern and each soil-cover complex is determined by the amount stored per unit area, after infiltration is satisfied, multiplied by the area for which trenches are recommended.

Surface detention by contour trenches decreases flood volumes and peak discharges. The volume of surface detention is subtracted from the present volume of runoff to determine the volume of runoff with planned improvements.

The effects of contour trenches on flood- and sediment-source areas is estimated in the field. In most cases, trenches are recommended to break up gully systems on severe erosion source areas. Their installation results in changing these erosion source areas to a lower class. Contour trenches reduce sedimentation rates because erosion rates and summer flood discharges are reduced downstream where channels are cutting.

c. Example of Treatment Evaluation. The physical survey of the watershed furnishes estimates of the average total ground cover density on subareas ranging in size from a few to thousands of acres both under present conditions and 50 years with a program of management, seeding and trenching, and no treatment. From infiltration tests, relative amounts of runoff (Pe) is known for every density of each soil-cover complex. The evaluation method merely combines the runoff under each design storm to give a watershed total which can be converted into a flood peak at the gage. In order to study the economics of each treatment, it is desirable to show the flood reduction after the program had been in for 1 year, 5 years, and other periods up to 50 years.

Compilation sheets, table 5.5, have been designed for use in computing the runoff with and without the program. After present conditions are evaluated, the 1- and 5-year programs can be totaled by a few incidental calculations. Only those areas which are to be trenched need be broken down separately since cover density is expressed as an average change over the whole subarea.

Average density for present conditions given and a total flood volume in acre-feet is obtained by multiplying the overland flow (Pe) in feet by the subarea in acres. For each watershed there is a relation between peak and volume of floods which enables the flood peak to be computed. A correction may be added for the amount of sediment carried by the water.

4. Example of Gully Stabilization. The purpose of gully stabilization is to control gully erosion. The effect of such cutting is to produce sediment loads in streams and indirectly to influence runoff characteristics. A highly developed system of gullies reduces the time of concentration during flash floods which increases peak flows. Thus the drainage density of a watershed may be increased by severe erosion. Drainage density or linear feet of minor channels per acre can be related to time of concentration of overland flow by formula, figure 5.11. Time varies inversely as the square root of drainage density in the equation. For example it can be shown that doubling the drainage density would cause about a 20-percent decrease in time. Peak flows by the unit hydrograph method would also change proportionately. Preventing future gully development can thus be evaluated by changes in expected peak flows. Stabilization measures which tend to reverse the process by increasing the time for runoff to flow over meadows instead of through a gully system can be evaluated by considering channel velocities in flood routing by the storage indication method, table 5.6.

Table 5.5.--(Sheet 1)

Effects of Land Treatment Program

(Terracing, seeding, improved mgt., fencing, etc.)

Present condition													With program (1 yr.)					With program (5 yrs.)								
DESCRIPTION				SURFACE RUNOFF BY STORM SIZES																						
Area No.	Parent Mat. & Cover	Area Acres	Density %	.50"		1.00"		1.50"		2.00"		2.50"														
				PE	RO	PE	RO	PE	RO	PE	RO	PE	RO	0.50"	1.00"	1.50"	2.00"	2.50"	Density %	0.50"		1.00"		1.50"		2.50"	
																				PE	RO	PE	RO	PE	RO	PE	RO
1	Herb	1,000	15	.0154	15.4	.0535	53.5	.0935	93.5	.1342	134.2	.1748	174.8	-	-	-	-	-	25	.0117	11.7	.0497	49.7	.0883	8.9	.1691	169.1
	Trench	989	5	.0212	21.0	.0607	60.0	.1020	100.9	.1418	140.2	.1837	181.7	-	-	-	16.6	58.1	25	.0117	-	.0497	-	.0883	3.9	.1691	43.6
2	Herb	1,630	15	.0154	25.1	.0535	87.2	.0935	152.4	.1342	218.7	.1748	284.9	-	-	-	-	-	23	.0124	20.2	.0506	82.5	.0892	1.7	.1702	277.4
	Trench	408	5	.0212	8.6	.0607	24.8	.1020	41.6	.1418	57.9	.1837	74.9	-	-	-	6.8	23.9	23	.0124	-	.0506	-	.0892	2.0	.1702	18.4
3	Herb	89	5	.0212	1.9	.0607	5.4	.1020	9.1	.1418	12.6	.1837	16.3	-	-	-	-	-	28	.0107	1.0	.0489	4.4	.0869	1.3	.1677	14.9
	Trench	268	5	.0212	5.7	.0607	16.3	.1020	27.3	.1418	38.0	.1837	49.2	-	-	-	4.5	15.7	28	.0107	-	.0489	-	.0869	0.7	.1677	11.4
4	Brush	3,440	35	0	-	0	-	0	-	.0042	14.4	.0250	86.0	-	-	-	-	-	39	0	-	0	-	0	2.6	.0194	66.7
	Trench	100	5	0	-	.0030	0.3	.0390	3.9	.0735	7.4	.1090	10.9	-	-	-	-	-	39	0	-	0		0	-	.0194	-
5	Brush	306	20	0	-	0	-	.0010	0.3	.0320	9.8	.0575	17.6	-	-	-	-	-	22	0	-	0	-	.0006	5.2	.0530	16.2
6	Sage	280	10	0	-	0	-	.0385	10.8	.0745	20.9	.1165	32.6	-	-	-	-	-	11	0	-	0	-	.0360	0.0	.1137	31.8
7	Brush	1,530	20	0	-	0	-	.0010	1.5	.0320	49.0	.0575	88.0	-	-	-	-	-	21	0	-	0	-	.0008	5.1	.0552	84.5
8	Brush	891	25	0	-	0	-	0	-	.0197	17.6	.0462	41.2	-	-	-	-	-	26	0	-	0	-	0	6.0	.0440	39.2
9	Brush	509	25	0	-	0	-	0	-	.0197	10.0	.0462	23.5	-	-	-	-	-	26	0	-	0	-	0	9.2	.0440	22.4
	Volume (acre-feet)			77.7		247.5		441.3		730.7		1081.6		-35.3	-101.4	-173.7	-215.6	-219.0		370.9		136.6		252.9		795.7	
	Peak (5.0 v + 70) (c.f.s.)			460		1310		2270		3720		5480								230		750		1330		4050	
	Reduction (%)													38.4	38.8	38.3	29.0	20.0								26.0	

* - PE = Precipitation Excess (depth in feet)
** - RO = Runoff (acre feet)

Table 5.5—(Sheet 2)

Effects of Land Treatment Program (Continued)

DESCRIPTION			With program (50 years)										Without program (50 years)									
Area No.	Parent Mat. & Cover	Area Acres	Density %	0.50"		1.00"		1.50"		2.00"		2.50"		Density %	0.50"		1.00"		1.50"		2.00"		2.50"	
				PE	RO	PE	RO	PE	RO	PE	RO	PE	RO		PE	RO	PE	RO	PE	RO	PE	RO	PE	RO
1	Herb	1,000	35	.0086	8.6	.0472	47.2	.0852	85.2	.1246	124.6	.1642	164.2	13	.0164	16.4	.0553	55.3	.0961	96.1	.1365	136.5	.1767	176.7
	Trench	989	35	.0086	-	.0472	-	.0852	-	.1246	-	.1642	38.8	5	.0164	21.0	.0553	60.0	.0961	100.9	.1365	140.2	.1767	181.7
2	Herb	1,630	35	.0086	14.0	.0472	76.9	.0852	138.9	.1246	203.1	.1642	267.6	12	.0170	27.7	.0562	91.6	.0952	155.2	.1358	221.4	.1761	287.0
	Trench	408	35	.0086	-	.0472	-	.0852	-	.1246	-	.1642	16.0	5	.0170	8.6	.0562	24.8	.0952	41.6	.1358	57.9	.1761	74.9
3	Herb	89	35	.0086	0.8	.0472	4.2	.0852	7.6	.1246	11.1	.1642	14.6	5	.0212	1.9	.0607	5.4	.1020	9.1	.1418	12.6	.1837	16.3
	Trench	268	35	.0086	-	.0472	-	.0852	-	.1246	-	.1642	10.5	5	.0212	5.7	.0607	16.3	.1020	27.3	.1418	38.0	.1837	49.2
4	Brush	3,440	40	0		0		0		0		.0180	61.9	34	0		0		0		.0056	19.3	.0270	92.9
	Trench	100	40	0		0		0		0		.0180	-	5	0		0	0.3	0	3.9	.0056	7.4	.0270	10.9
5	Brush	306	25	0		0		0		.0197	6.0	.0462	14.1	17	0		0		.0087	2.7	.0392	12.0	.0666	20.4
6	Sage	280	15	0		0		.0252	7.1	.0619	17.3	.1025	28.7	10	0		0		.0385	10.8	.0745	20.9	.1165	32.6
7	Brush	1,530	30	0		0		0		.0110	16.8	.0350	53.6	14	0		0		.0162	24.8	.0472	72.2	.0760	116.3
8	Brush	891	35	0		0		0		.0042	3.7	.0250	22.3	24	0		0		.0002	0.2	.0222	19.8	.0485	43.2
9	Brush	509	35	0		0		0		.0042	2.1	.0250	12.7	22	0		0		.0006	0.3	.0271	13.8	.0530	27.0
	Volume (acre-feet)			23.4		128.3		238.8		384.7		705.0			81.3		253.7		472.9		772.0		1129.1	
	Peak (5.0 v + 70) (c.f.s.)			190		710		1270		2000		3600												
	Reduction (%)			59.0		45.5		44.5		46.5		34.4			3.9		2.4		7.0		5.5		4.2	

The effect on water yield might be evaluated by computing the change in storage-discharge relations operating on streamflow. Gully and channel cutting create voids which can be measured. This volume of material removed by erosion from stream channels reduces the effective storage-controlling rates of runoff. Like in a well, the depth of cutting lowers the water table in the surrounding valley fill. This volume for water storage can also be estimated by formula or determined by field observation of drained meadows.

A storage-discharge relation can be drawn from the recession hydrograph of flow under present conditions. By routing the present runoff back through the appropriate storage curve, an inflow rate can be determined table 5.7. This apparent inflow can then be routed through another storage curve adjusted to a changed volume. For example, if the storage is doubled the future hydrograph would be markedly flattened, figure 5.12. Thus the seasonal changes in flow, due to erosion, can be computed. Stabilization measures which tend to reverse this process can be similarly evaluated.

Table 5.6--Effect of Gully Erosion in Peaking Runoff (Example)[1]

Time	Inflow	Mile 14^0-13^5		Mile 13^5-13^0		Mile 13^0-12^5		Mile 12^5-12^0		Outflow	
(5 min.)	(cfs)	With	Out	With	Out	With	Out	With	Out	With Gully	Without
										(cfs)	
5	25	0									
10	160	45	20	0							
15	810	400	200	65	10	0	0				
20	1830	1250	700	430	100	60	5	0			
25	2490	2000	1250	1150	350	400	30	50	0		
30	2540	2400	1750	1750	700	960	130	260	10		
35	2150	2150	1900	2100	1050	1500	350	660	35		
40	1740	1900	1800	2050	1250	1850	550	1150	100		
45	1360	1550	1600	1850	1400	1900	750	1600	220		
50	1030	1300	1450	1550	1450	1800	1000	1700	350		
55	710	950	1200	1350	1400	1550	1100	1700	550		
60	410	600	900	1000	1250	1350	1200	1550	700		
								1350	850		
								1150	950		
								950	1000		
								740	1000		
								580	975		
								450	950		
								370	900		

[1] Channel storage double in natural condition.

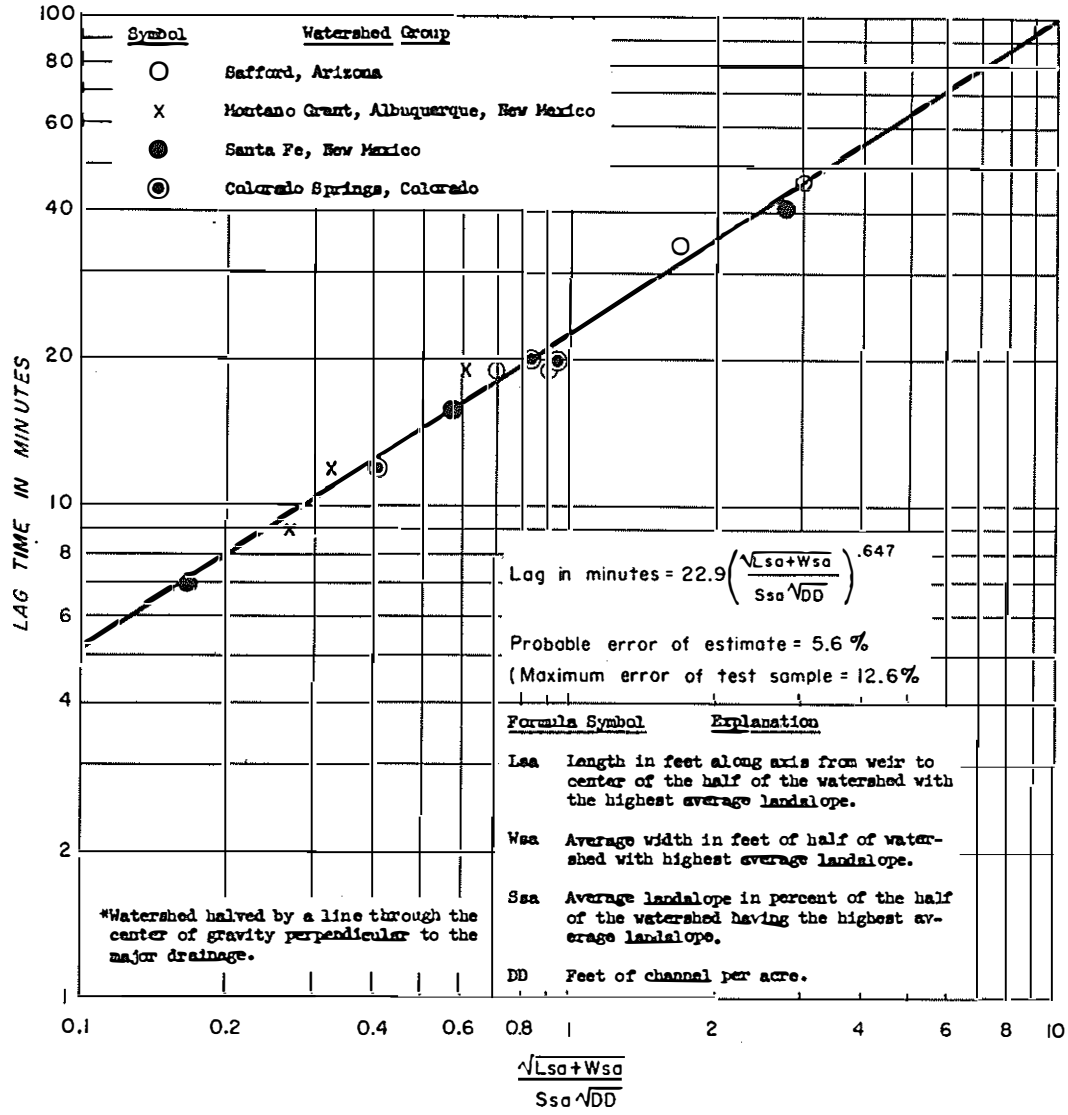


Figure 5.11 - Correlation of measured Lag Times with Basin Characteristics

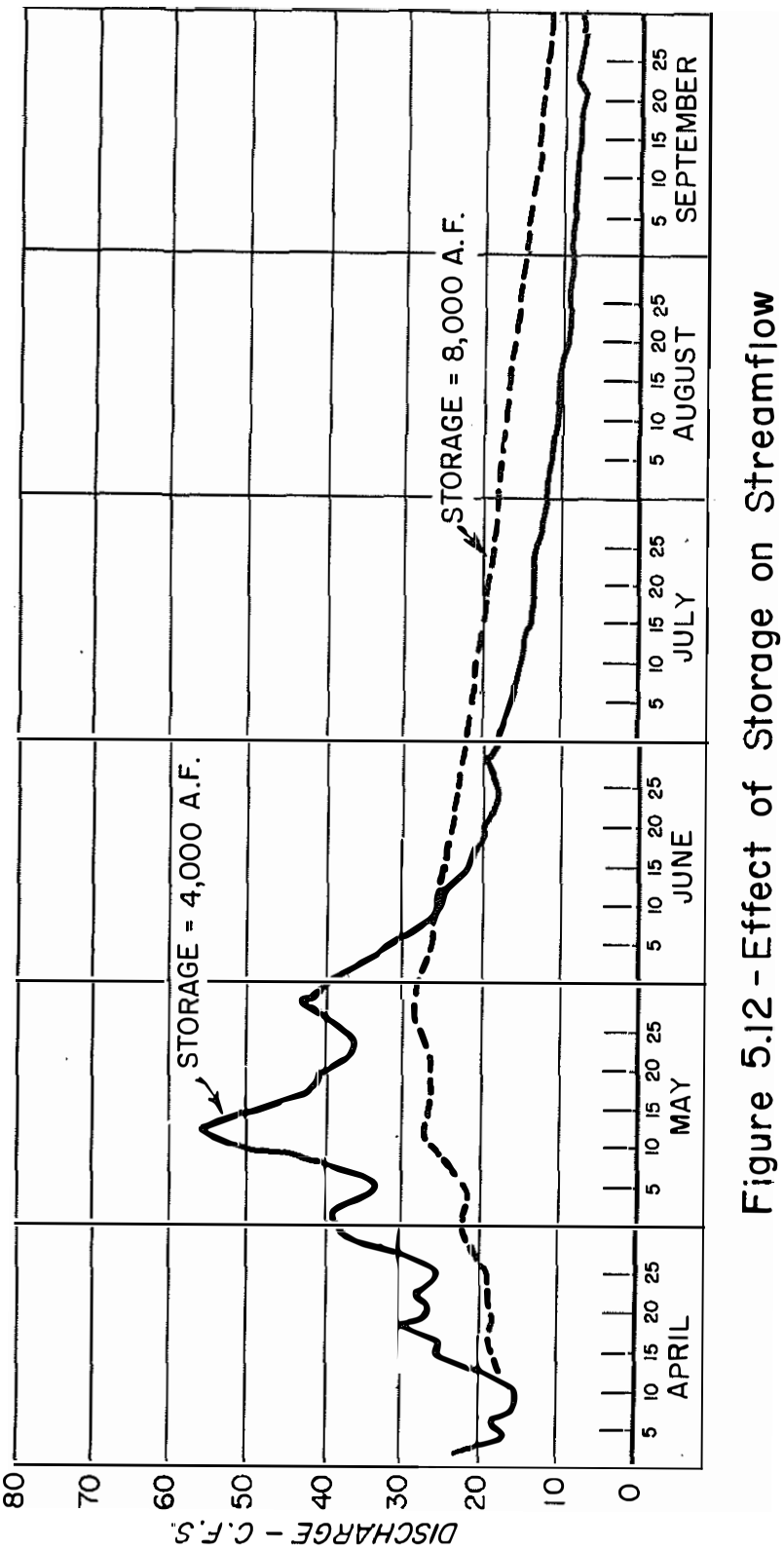


Figure 5.12 - Effect of Storage on Streamflow

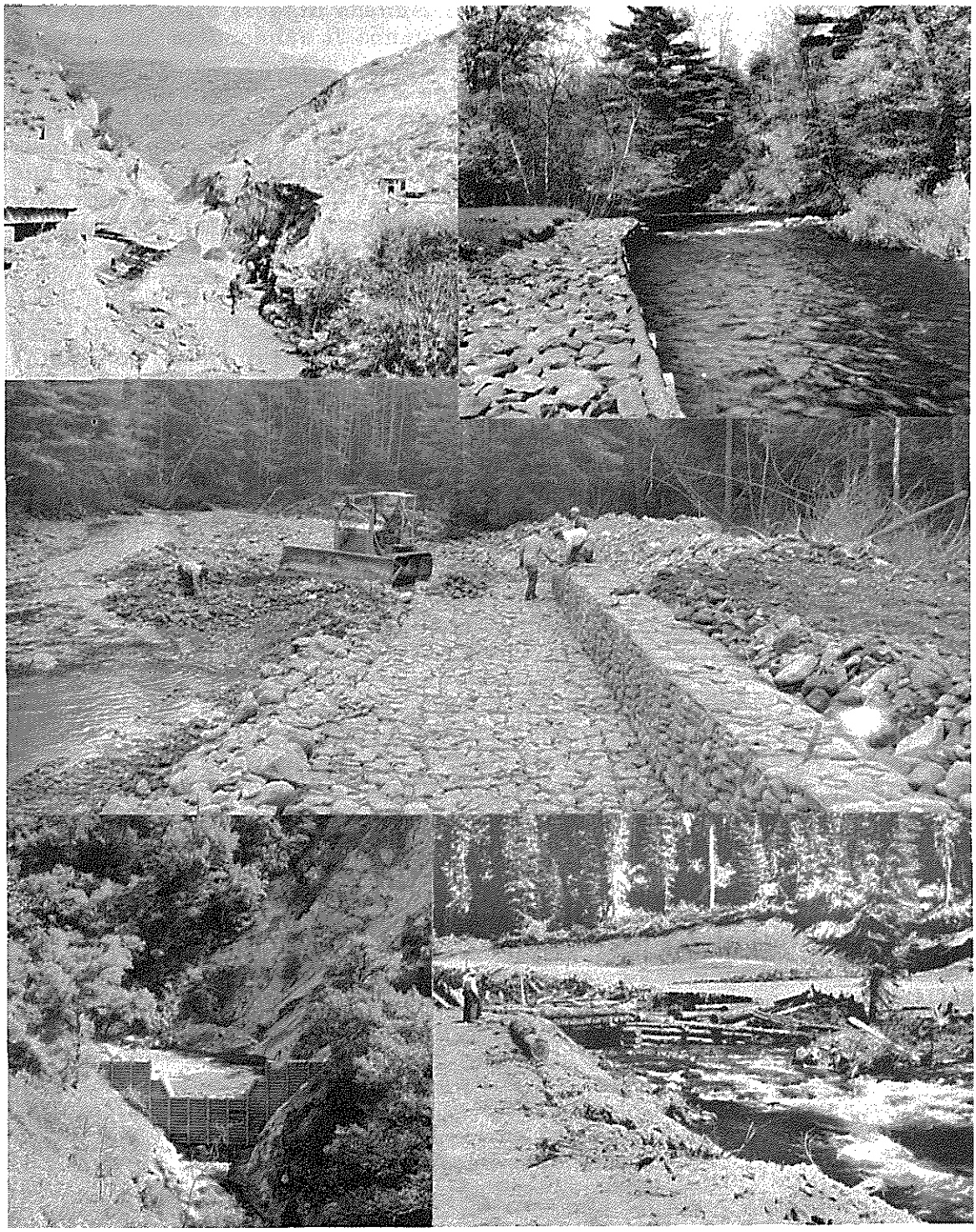
Table 5.7.--Effect of Groundwater Storage on Streamflow

Minimum Storage									Maximum Storage													
April			May			June			April			May			June			July			August		
I	S	O	I	S	O	I	S	O	I	S	O	I	S	O	I	S	O	I	S	O	I	S	O
	1470	19	39	1800	39	6	1780	37				39	3360	22	6	3785	27.5	14	3385	22	7	3015	18
	1550	23	7	1800	39	4	1750	35				7	3345	22	4	3760	27.5	14	3380	22	7		
	1470	19	5	1770	36	6	1720	33				5	3330	22	6	3740	27	6			7		
	1410	17	13	1740	34	7	1710	32				13	3320	21.5	7	3720	26.5	6		22	7		
	1410	17	64	1720	33	4	1670	30				64	3360	22	4	3700	26.5	6			7		
	1430	18	66	1750	35	8	1660	29				66	3405	22.5	8	3680	26.5	6			7		
	1410	17	110	1780	37	3	1640	28				110	3480	23.5	3	3660	26	6	3300	21.5	7	2950	17.5
15	1350	15	83	1850	42	26	1600	26	15	2700	15	83	3540	24.5	26	3660	26	7			4		
15	1350	15	118	1890	45	15	1600	26	15	2700	15	118	3630	25.5	15	3650	26	7			4		
45	1350	15	83	1960	52	17	1590	25	45	2730	15.5	83	3690	26.5	17	3640	25.5	7		21.0	4		
107	1380	16	65	1990	55	17	1590	25	107	2820	16.5	65	3730	27	17	3630	25.5	7			4		
80	1470	19	35	2000	56	0	1590	25	80	2885	17	35	3740	27	0	3605	25	7	3230	20.5	4	2900	17
83	1530	22	12	1980	54	3	1550	23	83	2950	17.5	12	3725	27	3	3585	25	8			5		
36	1590	25	18	1940	50	11	1530	22	36	2970	18	18	3715	26.5	11	3570	24.5	8			5		
15	1600	26	5	1910	47	21	1520	21	15	2970	18	5	3695	26.5	21	3565	24.5	8		20	5		
56	1590	25	3	1870	44	11	1520	21	56	3010	18.5	3	3670	26	11	3550	24.5	8			5		
65	1620	27	41	1830	41	10	1510	21	65	3060	19	41	3685	26.5	10	3535	24.5	8	3170	19.5	5	2840	16.5
	1680	30	41	1830	41	10	1500	20		3040	18.5	41	3700	26.5	10	3520	24	9			7		
	1640	28	10	1830	41	10	1490	20		3020	18.5	10	3685	26.5	10	3505	24	9			7		
26	1600	26	18	1800	39	10	1480	20	26	3030	18.5	18	3675	26	10	3490	24	9			7		
67	1600	26	27	1780	37	9	1470	19	67	3080	19	27	3675	26	9	3475	23.5	9			7		
7	1640	28	36	1770	36	9	1460	19	7	3070	19	36	3685	26.5	9	3460	23.5	9	3120	19	7	2790	16
6	1620	27	57	1770	36	18	1450	18.5	6	3060	19	57	3715	26.5	18	3455	23.5	8			7		
15	1600	26	38	1790	38	18	1450	18.5	15	3055	18.5	38	3725	27	18	3450	23.5	8			7		
36	1590	25	69	1790	38	19	1450	18.5	36	3075	19	69	3765	27.5	19	3445	23	8			7		
87	1600	26	71	1820	40	19	1450	18.5	87	3140	19.5	71	3810	28	19	3440	23	8			7		
91	1660	29	52	1850	4242	38	1450	18.5	91	3210	20	52	3835	28.5	19	3435	23	8	3065	18.5	7	2745	15.5
85	1720	33	33	1860	43		1490	20	85	3275	21	33	3840	28.5	19	3430	23	9			7		
57	1770	36	21	1850	42	0	1450	18.5	57	3310	21.5	21	3835	28.5	0	3405	22.5	9			7		
49	1790	38	10	1830	41	12	1430	18	49	3340	22	10	3815	28	12	3395	22.5	9			7		
			18	1800	39							18	3805	28				9	3025	18	7	2710	15

I = Inflow (c.f.s.) S = Storage (c.f.s. x hrs.) O = Outflow (c.f.s.)

CHANNEL CHANGES & STRUCTURES

CHAP. 6



CHAPTER 6

6 - EVALUATION OF CHANNEL CHANGES AND STRUCTURES. The function of a stream channel is to dispose of runoff water from the watershed. The stream channel is composed of two parts: The channel proper which, because it constantly carries water, is usually devoid of vegetal cover; and the flood plain which, because of the infrequency of use, may support cover or works of improvement such as road fills or even buildings. The efficiency with which the channel disposes of runoff water depends upon the size or cross sectional area, the slope, and the roughness or physical obstructions in the channel area. The flow may be intentionally retarded by dams which temporarily detain runoff water to control flood peaks or to make water available for beneficial use during the drier seasons of the year.

6.1 - Flood Plain. The flood plain is a part of the channel which is used only during relatively short periods of time when the rate and volume of runoff greatly exceeds the normal. The frequency of flood-plain use as well as the size, shape, and character of the flood plain may vary considerably from one watershed to another. Encroachment of the flood plain for agricultural, industrial, or municipal purposes results in millions of dollars of flood damage annually throughout the nation. In many places the periodic flooding may result in increased fertility of the soil and so enhance the crop producing capabilities of the flood plain as to make crop production a justifiable use of these lands. Even with a more complete loss of as much as one crop in three, this use may prove to be a well-calculated risk. In many places industrial and municipal buildings have been constructed in the flood plain because of land pressures or for convenience in cases where the stream-flow is used for the water supply or transportation of products. In many cases the flood plain has not been used for discharging flood flows in the memory of the local inhabitants, and longtime stream-gaging records give no warning of any potential flood threat. In many cases, however, industrial and municipal development and exploitation of the watershed lands take place subsequent to the flood-plain development. Man's activities on the watershed almost invariably reduced the watershed's water handling capabilities and downstream floods on the flood-plain result. When flood-plain damages reach intolerable proportions, measures are undertaken to prevent recurrences. Levees are built to prevent the stream from using its flood plain, and large dams are built to retard flood water and reduce flood peaks. Continued and accelerated erosion and sedimentation from the watershed land make these very costly types of remedy, at best, a temporary expedient. Under this false sense of security however the development of flood-plain improvements commonly proceeds at an ever accelerating pace. Very often little thought, and less action, is directed at restoring the water-handling capabilities of the watershed as one of the most effective but less costly means of reducing the hazards of flood damage to flood plain improvements.

6.2 - Function in Water Management. The stream channel receives water from the land and carries it downstream to be discharged into a larger stream, lake, or into the ocean. The character of the stream channel can play an important part in reducing or increasing flood flows. The stream channel acts as a retarding reservoir. The channel's temporary storage capacity varies with the cross sectional area and roughness or amount of obstruction in the channel, and inversely as the slope. The drainage pattern of watershed is important in this respect, since a highly developed channel system will store more water than a simple pattern of drainage. This is offset, however, by the fact that in a watershed having a highly developed channel system, runoff water reaches the channel with much less overland or subsurface flow. A relatively flat channel will store more water than a steep channel. The hydraulic effect of a channel upon flood runoff is discussed in greater detail under 6.4.

6.3 - Effect of Channel Size and Slope. Both the cross-sectional area and the shape of the channel affects the storage capacity and the hydraulic efficiency of the channel. A deep narrow channel will discharge water more rapidly than a broad shallow channel of the same cross-sectional area, because the land-surface area in contact with the water is smaller in proportion to the volume of flow. The length of the line of contact between water and the channel surface, measured on the channel cross section, is called the wetted perimeter. The value obtained by dividing the wetted perimeter by the cross-sectional area is called the hydraulic radius. The velocity in the channel varies as the two-thirds power of the hydraulic radius. The velocity of flow in a channel varies as the square root of the slope. The slope of a stream channel is not always constant, it may be reduced by increased meanderings of the stream channel, or may be increased by natural or artificial changes in channel alinement. In most streams the slope of the flood plain is appreciably flatter than in the channel proper. This fact greatly complicates the theoretical computation of channel discharge capacity.

The roughness of the channel bottom, the degree of meandering, and the amount of obstructions in the channel affect the discharge capacity. The combined effect of these three factors is expressed as a roughness coefficient of the channel when computing theoretical velocity. Channel velocity varies inversely as the roughness coefficient. This roughness coefficient is the most difficult of all channel characteristics to measure, and is often the source of appreciable error in theoretical computations, particularly, in small streams.

6.4 - Flood Routing. As a flood wave moves downstream it undergoes changes in shape which lengthen the base and lower the crest. Engineering problems frequently require a determination of the rate of travel and the changes in shape, so that, given a known hydrograph at some point on a stream the shape and time position of the hydrograph at some downstream point may be determined. Application of the general

equations of flood-wave movement to this problem is so complex as to force the use of approximate solutions for practical problems. The application of such approximate solutions for the reproduction of a downstream hydrograph is known as flood routing.

There are a number of approximate flood-routing methods, based on the principle that outflow from a stream reach during any time interval must equal the inflow into the reach plus or minus the change in storage within the reach. This type of flood routing procedure is more accurately termed storage routing. To simply illustrate the principle involved, imagine an ideal reservoir in which discharge is over a weir so that outflow rate is a function of head. As water enters the reservoir the water surface rises and discharge from the reservoir increases. Since some water is required to fill a reservoir, as long as the inflow is increasing the outflow would be less than the inflow. As the inflow rate begins to decrease, the pool elevation will continue to rise until the inflow and outflow rates are equal. The maximum outflow rate occurs at the time of maximum pool elevation, which is the time when inflow and outflow are equal.

Although the approximate storage routing methods are basically similar, they each have peculiarities in procedure which make them particularly adaptable to a certain type of problem. While it is impractical to discuss in detail here each of these procedures, the methods can be illustrated by several examples.

One method is a modified Goodrich-Wisler method, which employs a graphical solution to the storage equation in the form:

$$\frac{2S}{dt} - q_1 + I_1 + I_2 = \frac{2S}{dt} + q_2$$

where:

S = storage in the routing reach in c. f. s. hours
dt = the routing time interval in hours
I = inflow to the reach in c.f.s.
q = outflow from the reach in c.f.s. Subscripts 1 and 2 denote the beginning and end of the routing interval.

Discharge is related to stage and for various values of discharge, $\frac{2S}{dt}$ is computed and a curve of discharge vs $\frac{2S}{dt}$ plotted for the reach, as shown in figure 6.1.

By adding and subtracting the value of q to $\frac{2S}{dt}$ at various discharges, the curves of $\frac{2S}{dt} + q$ vs discharge and $\frac{2S}{dt} - q$ vs discharge can be defined. These two curves are the working curves for flood routing through the reach. They are used to solve graphically the storage routing equation.

An example of this procedure is shown on figure 6.1, starting with a value for q_1 of 600 c.f.s. which corresponds to a value of 3750 c.f.s. on the $\frac{2S}{dt} - q$ curve, measure a distance $I_1 + I_2$ (3000 c.f.s.) horizontally as shown, move up to the $\frac{2S}{dt} + q$ curve and read the value of q_2 (865 c.f.s.) on the discharge scale. The value of q_2 then becomes q_1 in the next time interval and the procedure is repeated. In this manner the outflow hydrograph from the reach can be computed from the inflow hydrograph to the reach.

The mechanics of tabulating the inflow and outflow discharges is shown in table 6.1. The reach travel time should be as nearly as possible an even multiple of and always greater than the selected routing interval. Another storage routing method is the storage indication method or modified "Puls" method which solves the storage equation in the form:

$$\frac{S_2}{dt} + \frac{q_2}{2} = \frac{S_1}{dt} - \frac{q_1}{2} + \frac{I_1 + I_2}{2}$$

This method is very similar to the modified Goodrich-Wisler method in the data required, the routing procedure and the resulting hydrograph.

The working curve of discharge vs $\frac{S}{dt} + \frac{q}{2}$ developed from stream cross sections, is shown in figure 6.2. The routing sheet, table 6.2, shows the tabulation required. The routing procedure consists of a series of solutions of the storage equation using the curve in figure 6.2.

An analytical approach to storage routing is represented by the Muskingum Method developed by McCarthy. In this method, storage values are replaced by expressions for storage in the form of coefficients. The basic equation becomes:

$$q_2 = c_0 I_2 + c_1 I_1 + c_2 q_1$$

where:

$$c_0 = \frac{KX - 0.5T}{K - KX + 0.5T}$$

$$c_1 = \frac{KX + 0.5T}{K - KX + 0.5T}$$

$$c_2 = \frac{K - KX - 0.5T}{K - KX + 0.5T}$$

$$C_0 + C_1 + C_2 = 1.00$$

K = center of mass--lag interval or approximately the travel time through the reach.

X = a dimensionless factor which expresses the relative effect of inflow and outflow upon the volume of storage. It varies from 0 for pure reservoir action, in which storage is entirely a function of outflow, to 0.5 for pure translation action without storage, as in the case of a prismatic channel where the flood wave moves downstream without change in shape.

T = routing interval.

In the example shown in table 6.3, K = 3.5 hours, X = 0.1, and T = 1.5 hours.

A very simple graphical method for flood routing is the Wilson method. This can be performed in a matter of minutes as follows: Plot the inflow hydrograph. Start the routing by placing a straightedge from a point of zero flow at T hours ahead of the inflow hydrograph, to a point on the inflow hydrograph at the midpoint of the first routing interval. Draw the line from the beginning to the end of the first routing interval on the outflow hydrograph. Repeat this procedure for succeeding routing intervals until the complete outflow hydrograph is drawn. The outflow hydrograph so developed can be replotted at its proper time position if desired. This is the Wilson method in its simplest form. Refinements of this method will produce more refined results.

There are a number of short-cut methods for flood routing based on time transportation, ratio of drainage areas, etc. In general it is better to shortcut one of the above procedures when desirable to save time or if only approximate results are required.

The storage indication method, for example, can be shortcut by using longer routing reaches, longer routing intervals, fewer cross sections, or fewer points on the cross section in computing storage.

To give a comparison of the relative accuracy of results by the four methods described above, a sample inflow hydrograph has been routed through a hypothetical reach by each of the four methods. The working sheets are shown for the modified Goodrich-Wisler method; table 6.1, the storage indication or modified "Puls" method, table 6.2, and the Muskingum or McCarthy method, table 6.3. The comparative results are tabulated in table 6.4, and shown graphically in figure 6.3. Since the hydrographs developed by the Goodrich-Wisler method and the storage indication methods are practically identical, only one is shown on figure 6.3.

6.5 - Channel Changes and Improvements. The water-carrying capacity of a channel can be increased in three ways; (1) by increasing the channel slope, (2) by enlarging the channel either by deepening or widening, (3) by removing obstructions which retard the flow of water. Increasing channel capacity by any of these methods is known as channel improvement.

Table 6.1--Routing Through Reach 1
By Modified Goodrich-Wisler Method

Time	Inflow into Head of Reach 1 I (c.f.s.)	$I_1 + I_2$ (c.f.s.)	Outflow From Reach I (c.f.s.)
12:00 N	0	0	0
1:30	220	220	20
3:00	860	1080	130
4:30	1350	2210	370
6:00	970	2320	570
7:30	600	1570	630
9:00	210	810	570
10:30	560	770	520
12:00 M	2350	2910	790
1:30 A.M.	2900	5250	1425
3:00	1800	4700	1800
4:30	730	2530	1585
6:00	625	1355	1230
7:30	1200	1825	1115
9:00	1050	2250	1110
10:30	760	1810	1035
12:00 N	300	1060	870
1:30 P.M.	0	300	650
3:00		0	475
4:30			350
6:00			255
7:30			190
9:00			145
10:30			100
12:00 M			70
1:30 A.M.			50
3:00			30
4:30			20
6:00			0

Table 6.2--Routing Through Reach 1 Modified Puls Method or Storage Indication Method

Time	Inflow into Head of Reach 1 I	$\frac{I_1 + I_2}{2}$	$\frac{S}{dt} + \frac{q}{2}$	O
12:00 N	0	0	0	0
1:30 P.M.	220	110	110	15
3:00	860	540	635	135
4:30	1350	1105	1605	370
6:00	970	1160	2395	575
7:30	600	785	2605	640
9:00	210	405	2370	570
10:30	560	385	2185	515
12:00 M	2350	1455	3125	800
1:30 A.M.	2900	2625	4950	1430
3:00	1800	2350	5870	1800
4:30	730	1265	5335	1580
6:00	625	677	4432	1235
7:30	1200	912	4109	1120
9:00	1050	1125	4114	1120
10:30	760	905	3899	1040
12:00 N	300	530	3389	880
1:30 P.M.	0	150	2660	650
3:00		0	2010	470
4:30			1540	350

Table 6.3--Routing Through Reach 1 By McCarthy or Muskingum Method

Time	Inflow	$c_0 I_2$ $.103 I_2$	$c_1 I_1$ $.282 I_1$	$c_2 q_1$ $.615 q_1$	Outflow
12:00 N	0	0			0
1:30	220	23	0	0	23
3:00	860	88	62	14	164
4:30	1350	139	242	101	482
6:00	970	100	380	296	776
7:30	600	62	273	477	812
9:00	210	22	169	500	691
10:30	560	58	59	425	542
12:00 M	2350	242	158	334	734
1:30 A.M.	2900	298	663	451	1412
3:00	1800	185	820	870	1875
4:30	730	75	504	1155	1734
6:00	625	64	206	1065	1335
7:30	1200	124	176	820	1120
9:00	1050	108	339	688	1135
10:30	760	78	296	697	1071
12:00 N	300	31	214	660	905
1:30 P.M.	0	0	85	557	642
3:00			0	395	395
4:30					243
6:00					150

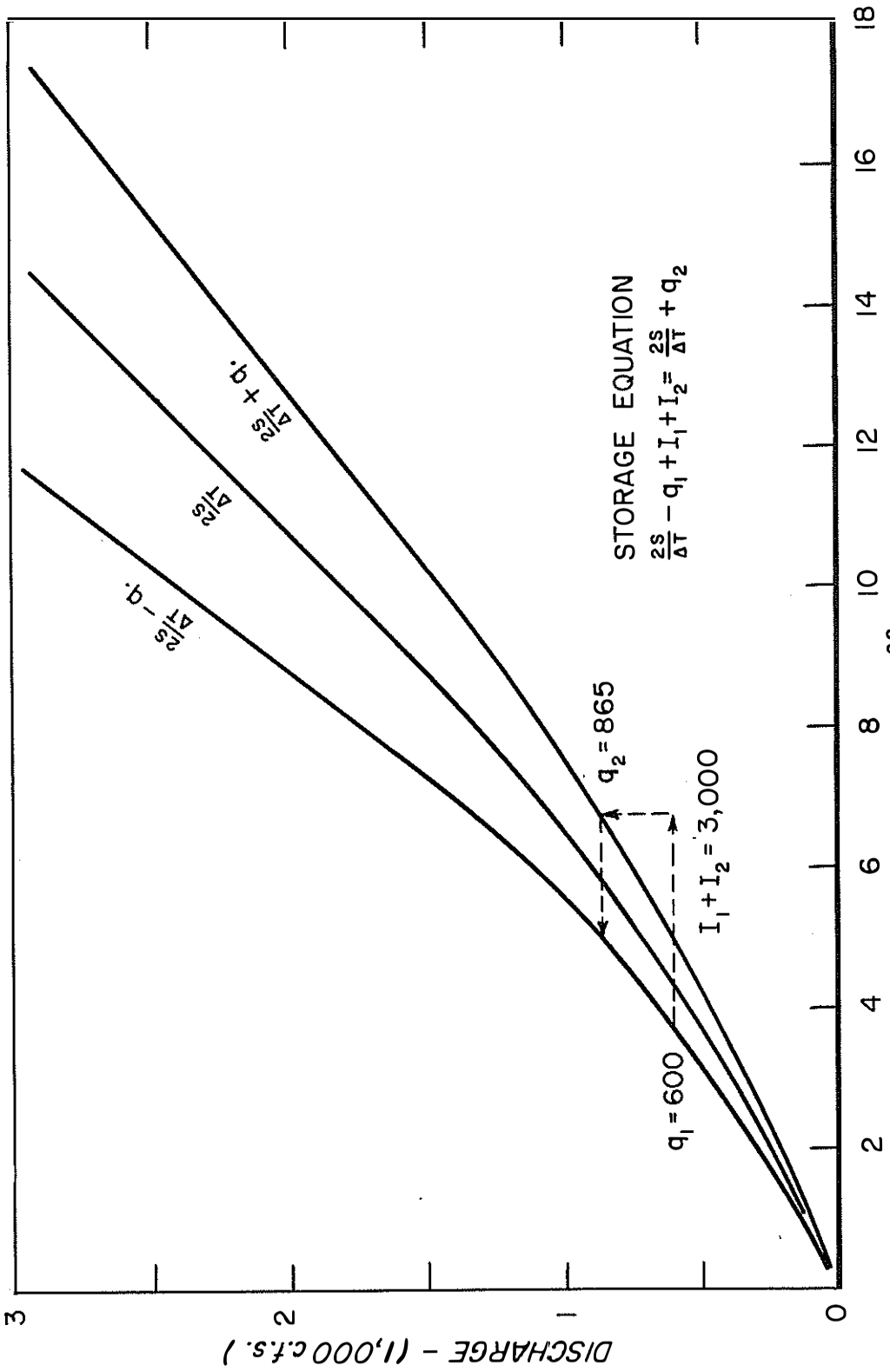


Figure 6.1 Modified Goodrich-Wisler Method, Routing Reach 1

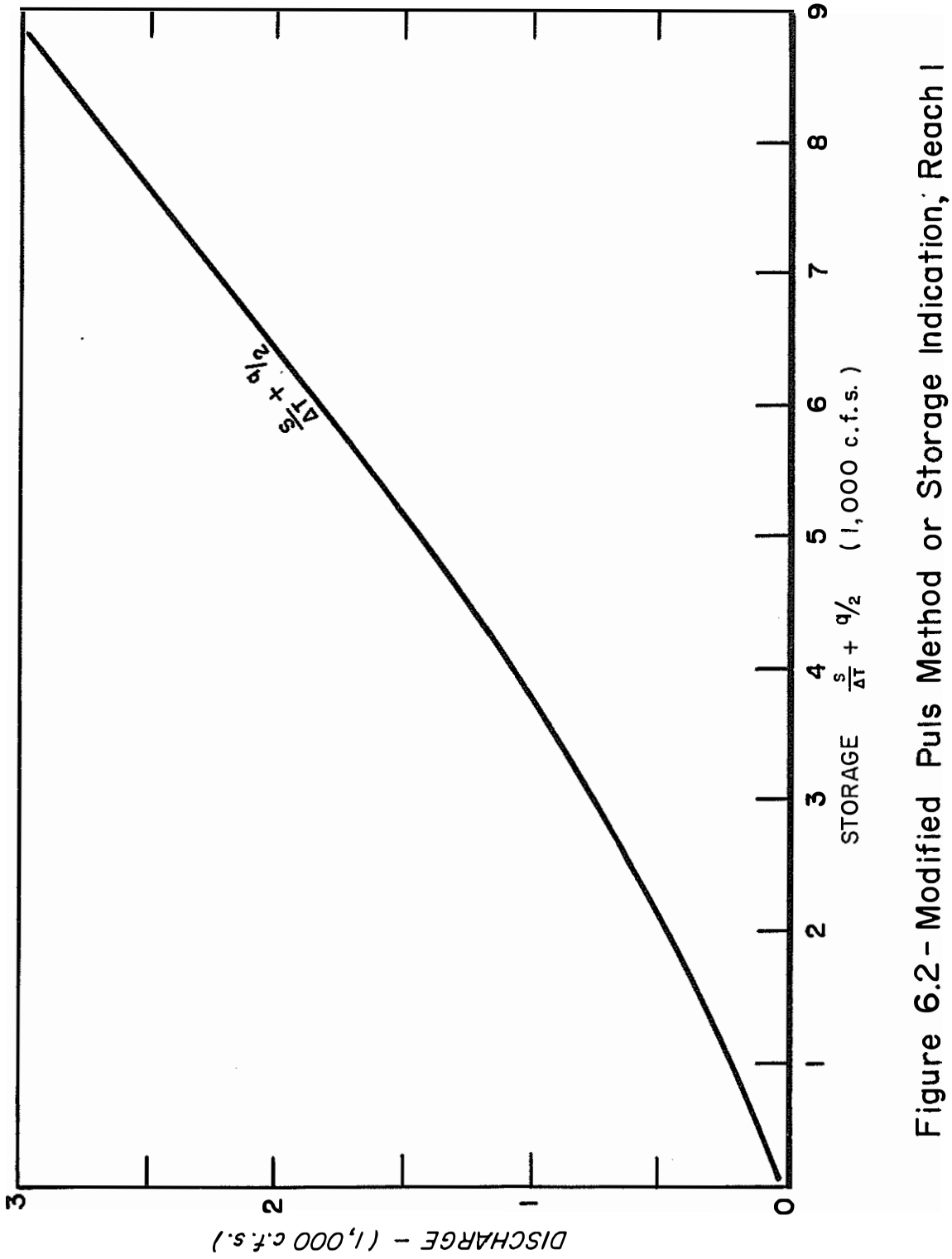


Figure 6.2 – Modified Puls Method or Storage Indication, Reach I

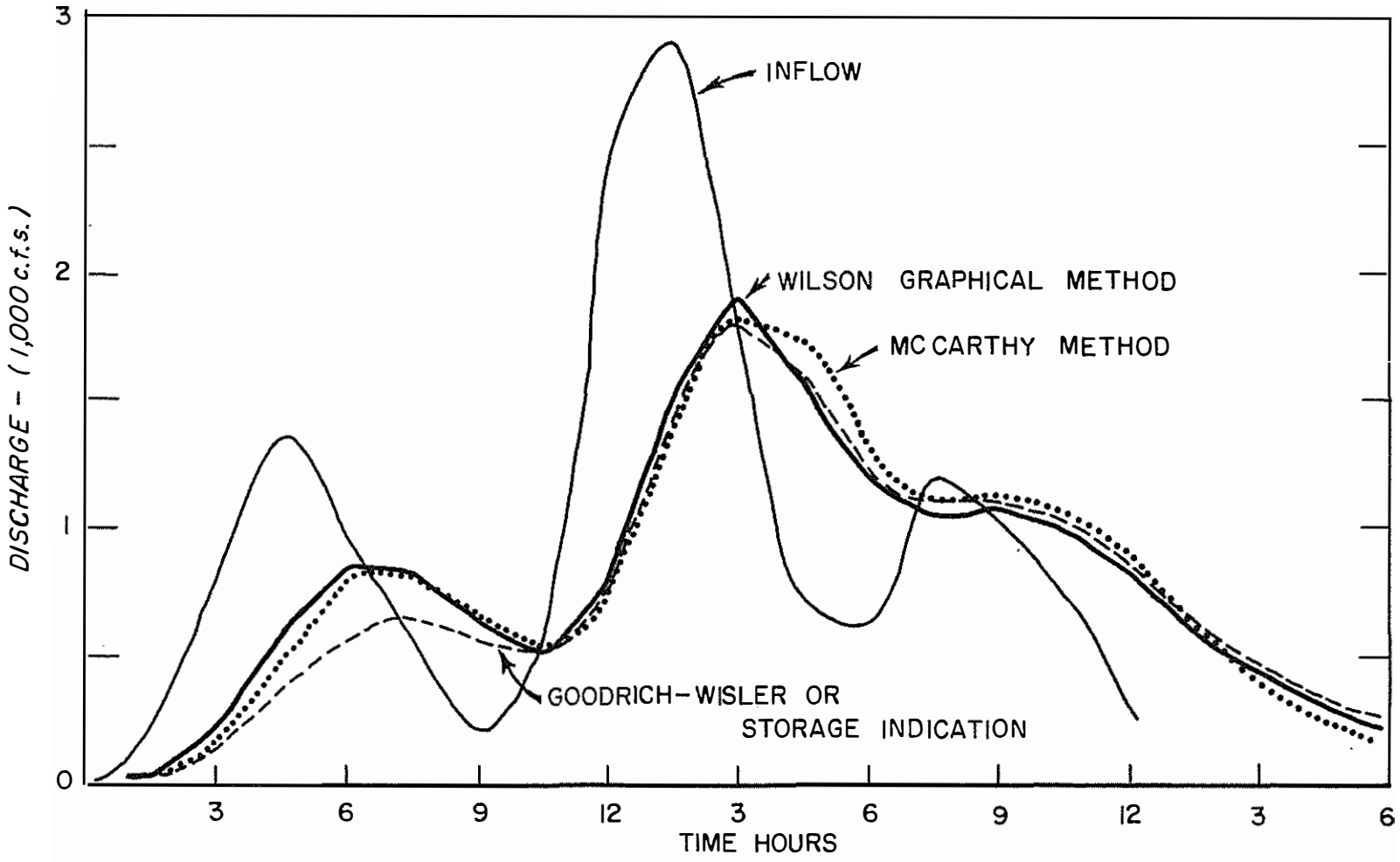


Figure 6.3 - Hydrograph routed by Wilson, Goodrich-Wisler, and Mc Carthy methods

Table 6.4--Comparison of Routing Methods

Time	Inflow to Head of Reach 1	Outflow from Reach 1 by Method of			
		Goodrich-Wisler	Storage Indication	McCarthy	Wilson Graphical
12:00 N	0	0	0	0	0
1:30 P.M.	220	20	15	23	25
3:00	860	130	135	164	220
4:30	1350	370	370	482	590
6:00	970	570	575	776	845
7:30	600	630	640	812	825
9:00	210	570	570	691	645
10:30	560	520	515	542	510
12:00 M	2350	790	800	734	785
1:30 A.M.	2900	1425	1430	1412	1570
3:00	1800	1800	1800	1875	1910
4:30	730	1585	1580	1734	1590
6:00	625	1230	1235	1335	1200
7:30	1200	1115	1120	1120	1060
9:00	1050	1110	1120	1135	1090
10:30	760	1035	1040	1071	1025
12:00 N	300	870	880	905	850
1:30 P.M.	0	650	650	642	600
3:00		475	470	395	430
4:30		350	350	243	310

In planning channel-improvement works, consideration must be given to the upstream and downstream effects of such changes. Such effects may be considerable, far reaching, and not always desirable.

The slope or gradient of a channel is most easily changed by constructing artificial cutoff channel to eliminate meanders in a stream. Such a change almost invariably results in accelerated erosion within an upstream from the cutoff, and deposition downstream. Such a cutoff also increases the water stage downstream. These potential adverse effects should be weighed against the benefits to determine the desirability of such a channel improvement.

The capacity of a channel can also be improved by increasing the cross-sectional area. For the same increase in area deepening is more effective than widening. Enlargement of the channel by widening, however, is normally accompanied by less drastic effects above and below the channel change.

Channel capacity can also be increased by removing obstructions from the stream channel. Such obstructions may be in the form of trees, large rocks, or logs and other debris. The removal of obstructions in a short section of channel is normally accompanied by a decrease in water depth above the section and an increase in depth below.

Channel improvement by any of these three methods is very often detrimental to fish life, because it removes hiding and resting places and increases channel velocity which cause scouring of the stream bottom and removal or damage to fish food.

The planning and evaluation of a channel change is not a job for a novice. The potential effects of a channel change are a matter of some conjecture even to an engineer familiar with stream channel hydraulics. Some of the basic principals to be considered are as follows:

1. When the channel slope is doubled, velocity is increased fifty percent, the cutting power of the water is increased two hundred percent, the quantity of material is increased sixteen hundred percent, and the size of particles that can be carried is increased thirty-two hundred percent.

2. Removal of obstructions from a channel increases the water velocity.

3. In a straight uniform channel the maximum velocity occurs at the water surface in the middle of the stream. On a curve the maximum velocity is near the outside. It is a matter of common observation that more erosion occurs on a streambank along the outside of a curve than on a straight section. For this reason, and because of the increased velocity induced by straightened channel section, the first point of curvature below a straightened channel section is normally the main trouble spot.

4. Velocity increases with water depth, therefore, constriction of a stream channel as by a roadfill increases depth and velocity.

One of the most common examples of a channel change is that occasioned by construction of a road along a narrow stream bottom. Such conflict should be avoided whenever possible through proper road location. When conflict is unavoidable, measures must be taken to protect the roadfill from the impact of the stream and also to protect the stream from impact of the road. The problem is complicated by the fact that the conflict invariably occurs at the outside of a bend in the stream.

When the length of contact between the stream and the roadfill is relatively short, the roadfill can be protected by riprap. When the roadfill appreciably restricts the channel, the stream should be widened on the other side to restore the original cross-sectional area. Care should be taken to avoid unnecessary disturbance of the stream channel during construction. When properly done, this type of change seldom results in serious damage. When the length of contact between the stream and roadfill is several hundred feet or more, or when the fill cuts off a meander in the stream, the problem is much more serious. The road fill can be protected by riprapping the same as on a shorter section, however, widening of the channel to restore the original cross section may not be adequate to prevent stream damage. If the length of the channel has been appreciably shortened, the velocity must be reduced to restore the original travel time. This might be accomplished in one of three ways; (1) if there is room in the channel bottom, the meander of the stream may be reproduced, (2) the channel may be widened in excess of its original width to reduce the depth and velocity of flow; (3) large boulders or other obstructions may be placed in the channel to obstruct the flow and reduce the velocity. In any case, the time and money expended on such a project should be commensurate with the character of the existing channel. Obviously, a considerably greater expenditure of time and money can be justified to protect a stable stream which has had no previous damage, than on one which has already been violated and become unstable as the result of past violations of a similar nature.

6.6 - Hydrologic Evaluation of Structures. Structures which may have a hydrologic or hydraulic effect upon stream channels are dams, levees, culverts, and bridges. Dams may be divided into five types depending upon the purpose for which they are built: irrigation, power, flood-water detention, stock ponds, and debris basins.

The irrigation dam normally stores water during the spring runoff periods for use during the dry season of the year. This type of dam stores a large percentage, if not all, of the runoff from the watershed above it. Discharge is normally controlled manually. This type of structure usually greatly reduces or eliminates flood flows on the stream channel immediately below. The rate of discharge can and should be controlled to such flows as the stream channel below can safely carry, without

damage. This type of structure has a marked effect upon streamflow below the structure since most of the stored water is lost through evaporation and seepage or used for irrigation.

Power dams are constructed to concentrate the fall in a stream at a particular point for the generation of power. They may also be built to provide storage for regulation of streamflow through the period of low runoff. Dams which provide head only, often affect streamflow very little. Those which provide storage as well, reduce downstream water supplies through evaporation losses from the reservoir surface. However, such reductions are of lower magnitude than those caused by irregular reservoirs.

Floodwater-detention dams provide temporary storage of floodwater and may have either controlled or automatic discharge. They are designed to reduce or eliminate downstream flood peaks, and discharge water at a rate which the channel can safely carry. Such dams are properly used as a supplement to a land management program, to control flood runoff from storms which exceed in volume and intensity the water handling capabilities of the soil and vegetation. When used as a substitute for a land management program, they are, at best, only a temporary expedient. Floodwater detention reservoirs may be designed to protect cropland or improvements immediately below, or at a considerable distance downstream.

The effects of floodwater-detention dams upon flooding immediately downstream are quite easily determined, but the analysis of effects far downstream is considerably more complex. When dealing with floods caused by snowmelt runoff, the downstream effect of a reservoir is proportional to the volume of water stored. When dealing with floods caused by rainstorms, the timing of flood flows is of paramount importance. Under such conditions, the effect of an individual reservoir will vary considerably, depending upon the distribution of rainfall over the watershed. A detention reservoir may, under certain conditions, actually increase flooding at some point downstream.

Stock ponds are constructed to retain water on grazing lands for the use of livestock. The quantity of water retained is usually relatively small. However, since it is often entirely consumed by stock or lost through evaporation, the effect of a large number of such structures upon flood runoff and downstream water supply particularly in arid regions, may be appreciable.

Debris basins are constructed to trap mud and rock flows and thus protect downstream channels and improvements. They are very often temporary expedients necessitated by an inadequate program of land use on the watershed.

Levees are embankments along streams or on flood plains designed to confine a river flow to a definite channel for the protection of surrounding

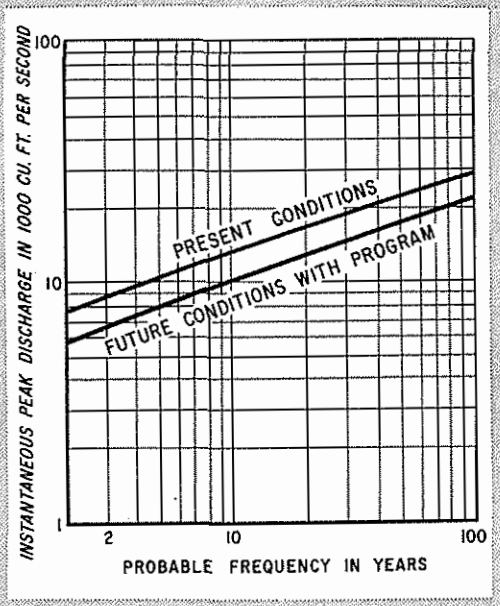
land. Levees increase the water depth and velocity through the levee section. They increase the rate of travel of the flood wave. They increase the maximum discharge at all points downstream, and decrease the surface slope of the stream above.

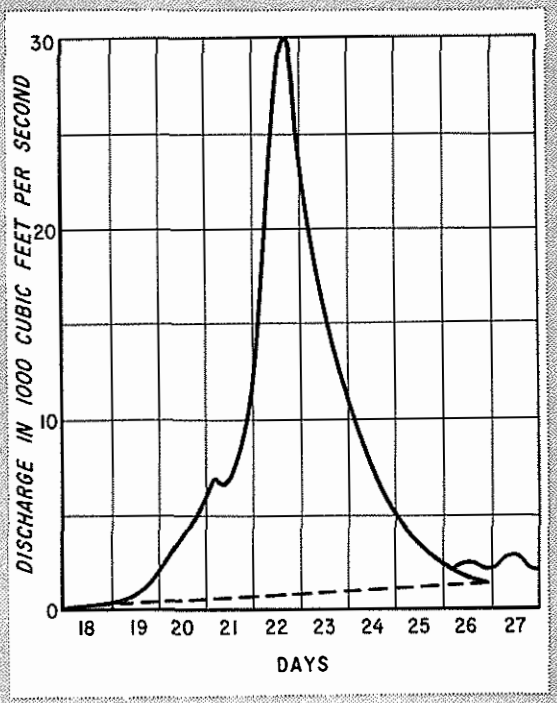
Culverts and bridge piers and abutments represent constrictions in channel which, if improperly designed, may have serious impacts upon the hydraulics of channel flow.

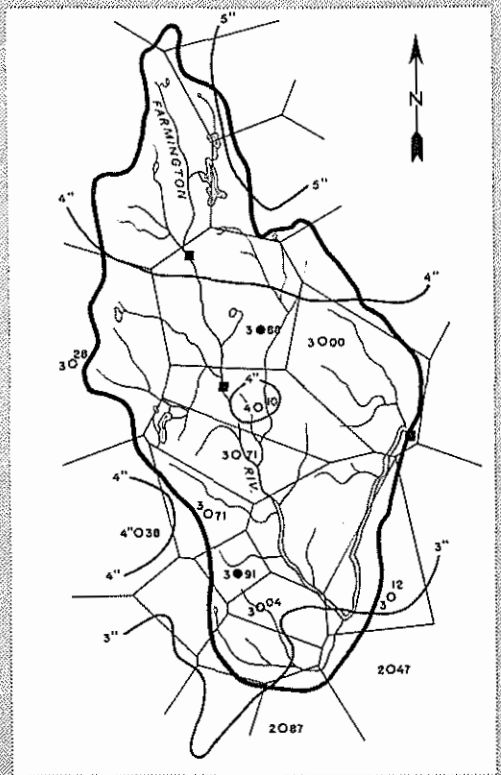
Adverse effects of dams, levees, culverts, and bridges can be reduced or eliminated by intelligent application of the basic principles of hydrology and stream-channel hydraulics.

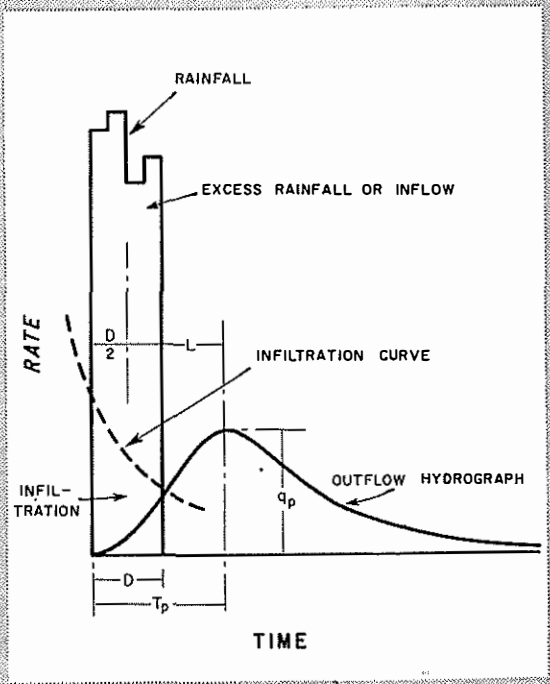
HYDROLOGIC ANALYSIS OF WATERSHEDS

CHAP. 7









CHAPTER 7

7 - HYDROLOGIC ANALYSIS OF WATERSHEDS

7.1 - Introduction. Chapters 1 through 6 of the handbook contain numerous examples of methods and procedures used in the process of making hydrologic appraisals of watershed conditions and of the probable effect of improvement programs.

The purpose of this chapter is to describe ways by which the several phases of watershed hydrologic study are combined into a single analysis to determine the effect of watershed conditions over a given area upon streamflow and peak discharges from that area. The basic elements of such an analysis are illustrated by examples such as the hydrologic aspect of fire-damage appraisal in California and flood control surveys in Oregon and California.

Other similar studies are available and may be useful in the hydrologic analysis of watersheds in other Forest Service regions.

FSH 3502 and National Engineering Handbook No. 4, "Hydrology" (SCS) provide detailed instructions on methods and procedures for the more technical aspects of watershed hydrologic analyses.

7.2 - Effects of Watershed Characteristics on Peak Discharge.[1] In southern California, discharge measurements adequate for determining frequencies of peak discharges are usually available for only part of the watersheds near the one being surveyed. Estimates of normal peak discharges for the other watersheds can be based on numerical ratings of the effect of various watershed physiographic factors on peak discharge. The ratings are derived from analyses of discharge data and the physiography of watershed units with streamflow records. The ratings are determined by storm zones, and are an expression of the effects upon peak discharge of local differences in watershed topography, soil, geology, and precipitation.

The determination and application of the watershed ratings in this example in southern California were aided by several conditions of the study. (1) Peak discharge was expressed in terms of unit area (cubic feet per second per square mile), thus permitting direct comparison of the effects of differences in watershed characteristics on these discharges. (2) Although rates of peak discharge varied with local differences in the watersheds, the general pattern of hydrologic behavior was similar, particularly for watersheds within the same storm zone. (3) Records of streamflow were available for nearly all of the larger, more important watersheds for which peak discharge was the most variable and difficult to estimate. (4) Watersheds for which discharge records were available were rather evenly distributed throughout each storm

[1] Rower, P. B.; Countryman, C. M.; and Storey, H. C.; "Hydrologic Analysis Used toDetermine the Effect of Fire" California Forest and Range Experiment Station, 1954.

zone, thus providing a reasonably complete sample of conditions existing in the watersheds included in the study.

Each of the watershed factors to be rated was subdivided into classes. Class division of some factors, such as watershed size, were based on actual areas of the units involved. Many of the factors, such as watershed shape, could only be classified qualitatively. The classes of these factors were assigned numbers, the class numbers indicating the relative effect of the class on peak discharge. Thus Class I would indicate effects tending to produce the highest discharges; Class II, effects tending to produce next highest, etc. The number of classes in each breakdown, except those in which the actual dimensions were used, was contingent upon the range of conditions encountered and their estimated effects on normal-peak discharge. A representative watershed of each class was selected as a model to facilitate the classification of other watershed units.

Topographic factors considered in the watershed ratings included (1) size in square miles, (2) shape (fan, rectangular, etc.), (3) density of surface-water sources (number and length of channels per-unit area), (4) average gradient of side slopes, (5) flow characteristics of principal stream channels. The effects of some factors like length of stream channels were excluded from individual consideration because they were reflected in other retings, such as those of watershed size and shape.

Soil factors considered in the watershed ratings included (1) relative infiltration capacity, and (2) water-storage capacity (wilting point to field capacity plus 1/4 storage between field capacity and field saturation).

The limits of the infiltration and water-storage classes of the different soil formations were established on the basis of soil textures, depths, and the results of past infiltration and soil moisture sampling.

Geologic factors included (1) relative permeability (infiltration capacity), (2) water storage capacity (maximum retention), and (3) amount of rock outcrop. Other differences in the soil and geologic factors, such as drainage characteristics, also influenced peak discharge, but these effects were small or were reflected in other ratings.

Relative permeability of the different geologic (rock) formations was determined by comparing the amounts of penetration of storm precipitation in watersheds containing rock substratum representative of the different formations but with other factors such as slope, topography, cover, etc., approximately the same. Only major storms with high amounts and rates of rainfall were used for this purpose. Rainfall penetration into the substratum during a storm (F_s) was assumed to be equal to the "storm rainfall" (P_s) less the sum of any "increase in soil water storage" (M_i) plus "storm interception loss" (I_s) plus "storm runoff" (Q_s), all expressed in inches depth, or $F_s = P_s - (M_i + I_s + Q_s)$. The

results of a series of such calculations for the different geologic formations permitted determination of their relative permeability and establishment of permeability classes.

Both types of vegetation and density of the cover were considered important factors in watershed performance. However, there proved to be a close correlation between type and density of the cover. Preliminary vegetation rating classes, therefore, were based solely on the mean areal density of the unburned watershed cover.

Precipitation classes were expressed in terms of the average annual rainfall, in inches deep, of the respective watersheds. Reasons for the use of the actual rainfall data are explained in the succeeding discussion of the watershed ratings.

Watershed Ratings in Terms of Peak Discharge. After the watershed rating factors for each storm zone were established and divided into standardized rating classes, the ratings for each unit were assigned and tabulated as illustrated for a sample watershed in table 7.1. The numerical significance of each class rating was determined by comparing normal peak discharges of a watershed with other watersheds that were similar in all hydrologic characteristics except the one being evaluated. These numerical ratings were expressed as ratios to the corresponding peak discharge of the key watershed. The ratings thus determined indicated the effect of differences in each factor on peak discharge but did not constitute a measure of the total effect of all differences on peak discharge.

Variation in amounts of watershed precipitation was one of the more important factors contributing to differences in normal peak discharge. Because of this the precipitation ratings were the first to be determined. This was accomplished by segregating watersheds, for which suitable streamflow records were available, into three groups; (1) watersheds with topographic, soil, and geologic characteristics estimated to be similar to those of the key watershed except for differences in amounts of precipitation, (2) watersheds with topographic, soil, and geologic characteristics estimated to be favorable to slightly higher discharge peaks than from the key watershed, and (3) watersheds with topographic, soil, and geologic characteristics estimated to be favorable to slightly lower peaks than from the key watershed.

Table 7.1--Use of Watershed Ratings in Computing Peak Discharge

(1) Items	(2) Rating classes		(3) Ratings for sample watershed[1]			
	(a) Key watershed	(b) Sample watershed	(a) Very small discharge[2]	(b) Small discharge[3]	(c) Medium discharge[4]	(d) Large discharge[5]
1. Topographic factors						
a. Size	[6] 10.6	[6] 26.7	.83	.88	.92	.94
b. Shape	I-	IV-	.56	.68	.78	.84
c. Density of surface water courses	II	II	1.00	1.00	1.00	1.00
d. Average gradient of side slopes	II	II	1.00	1.00	1.00	1.00
e. Flow characteristics of main channel	II-	III-	.90	.94	.97	.97
f. Average gradient of main channel	III+	III-	1.00	.99	.99	.99
2. Soil-geologic factors						
a. Soil infiltration capacities	IV+	IV	1.00	1.00	.98	.96
b. Soil water storage capacities	II	II-	1.00	.99	.96	.94
c. Rock permeability	III+	IV+	1.00	.99	.94	.92
d. Rock water storage capacities	IV-	V	1.00	.99	.96	.94
e. Rock outcrop	III	II	1.00	1.00	1.04	1.06
3. Precipitation factor	[7] 36.6	[7] 32.6	.91	.91	.91	.91
4. Integrated topographic, soil-geologic, and precipitation ratings			.20	.37	.45	.47
a. Peak discharge of key watersheds, c.s.m.			.81	33.5	152.0	389.0
b. Computed peak discharge of sample watershed, c.s.m.			.16	12.4	68.0	183.0

[1] Ratings expressed as ratios of peak discharge of sample watershed to corresponding discharges of key watershed.
[2] Peak discharge of size equaled or exceeded an average of ten times each year.
[3] Peak discharge of size equaled or exceeded an average of once each year.
[4] Peak discharge of size equaled or exceeded an average of once each 10 years.
[5] Peak discharge of size equaled or exceeded an average of once each 100 years.
[6] Area in square miles.
[7] Precipitation in inches depth.

Determination of the effects of fire on peak discharge were made in order to predict the most probable peak discharges of individual watersheds by years, from time of burning until complete recovery of the watershed. Since burning has no effect on storm frequency the only difference in the discharge frequency curve for a unit before and after burning is in the size of the average discharge for each frequency class. The average discharge per class can be expected to change from year to year as the watershed recovers from the fire.

The effect of complete burning of watersheds cover was determined by (1) comparing peak discharge rates of burned watersheds with those of similar but unburned watersheds for the same storm, and (2) comparing peak discharge rates from similar storms on the same watershed before and after burning. Watersheds used in these determinations were restricted to those in which the total watershed area had been burned over within a single year, in which measurements of streamflow were available for the burned and comparable unburned watersheds, and in which the normal vegetative cover consisted of chaparral associations of average density.

These comparisons were made storm-by-storm by years after the last fire. Similarity of watersheds was judged by comparison of normal discharge frequency curves and watershed ratings. Comparative watersheds were always close to or adjacent to the burned units.

The most probable size of each peak discharge event of the burned watershed had the unit remained unburned was first determined. The frequency of each discharge peak from a burned watershed was assumed to be the same as the frequency of the corresponding peak from the key and other nearby unburned watersheds. Using this frequency as estimated peak for the burned unit in an unburned condition could be read directly from its normal frequency curve. The ratio of the observed peak of the burned unit to the computed peak for unburned conditions was then calculated to obtain the fire-effect ration. This procedure of computing peak discharges following burning automatically corrects for differences in the physiographic characteristics of the watersheds for as previously shown these are reflected in the normal curves.

Similar fire-effect ratios were also developed by comparing peak discharges occurring from watersheds before complete burning with those occurring in the same watersheds after burning. The similarity of storms was established on the basis of uniformity in amounts of maximum 24-hour and total-storm precipitation, occurrence of the storms in relation to antecedent precipitation and time of year, and similarity in size of storm peak discharges in the key and in adjacent unburned watersheds of the storm zone.

The fire-effect ratios were plotted over their corresponding frequencies on logarithmic paper for all years after burn for which data

were adequate. Variations in the ratios within years were eliminated by fitting a smooth curve to the plotted points. Thus a series of curves giving average fire-effect ratios by discharge frequency classes and years after burn was developed, figure 7.1.

To smooth out differences in rates of change in the ratios between years and to provide ratios for years for which data were inadequate, ratios for each frequency class were read from the curves and plotted over time in years. Smooth curves were then drawn through these data. Ratios read from these curves were then replotted in their original form and the recovery curves redrawn as illustrated in figure 7.1 for selected years following burning. The fire-effect ratios as given by these final curves were used as the basis for computing the average, or most probable peak discharge, for all watersheds within the storm zone.

A period of 70 years was used as a standard recovery-from-fire period for all watersheds. This was done to simplify both the peak flow and damage-rate computations. Although it was recognized that the recovery period would vary between units, the comparatively small fire effect after the first few years and greatly increased computational work did not appear to justify the refinement of using varying recovery periods.

Peak discharge-erosion rate curves were developed for additional watersheds of the south slope storm zone for which data were available. Although these curves represented a wide sample of south-slope watersheds, they showed very little variation when superimposed. The curves were, therefore, used to develop a single mean curve to represent the average relations between normal peak discharge and erosion rates for all the south-slope watersheds of the zone. This mean curve varied only slightly from that shown for Santa Anita Canyon in figure 8.4 of the following chapter. Using the peak discharge-erosion rate curve as a base, normal erosion for each individual watershed was computed from its normal peak discharge frequency curve.

7.3 - Peak Discharges Correlated With Cover Conditions.[1] To develop a hydrologic basis for evaluation of flood control program of the U. S. Department of Agriculture in southern California, analyses of peak discharges and sedimentation for selected storms and watersheds were made.

The study consisted of 2 parts: (1) Study of flood causes, and (2) application of results of study to determine peak discharge frequency and sedimentation from individual specific watersheds.

In the flood-cause study, storms were selected to give full representation of storms of 3 size groups; small, medium, and large on dry,

[1]H. W. Anderson "Flood Frequency and Sedimentation From Forest Watersheds," A. G. U., 1949.

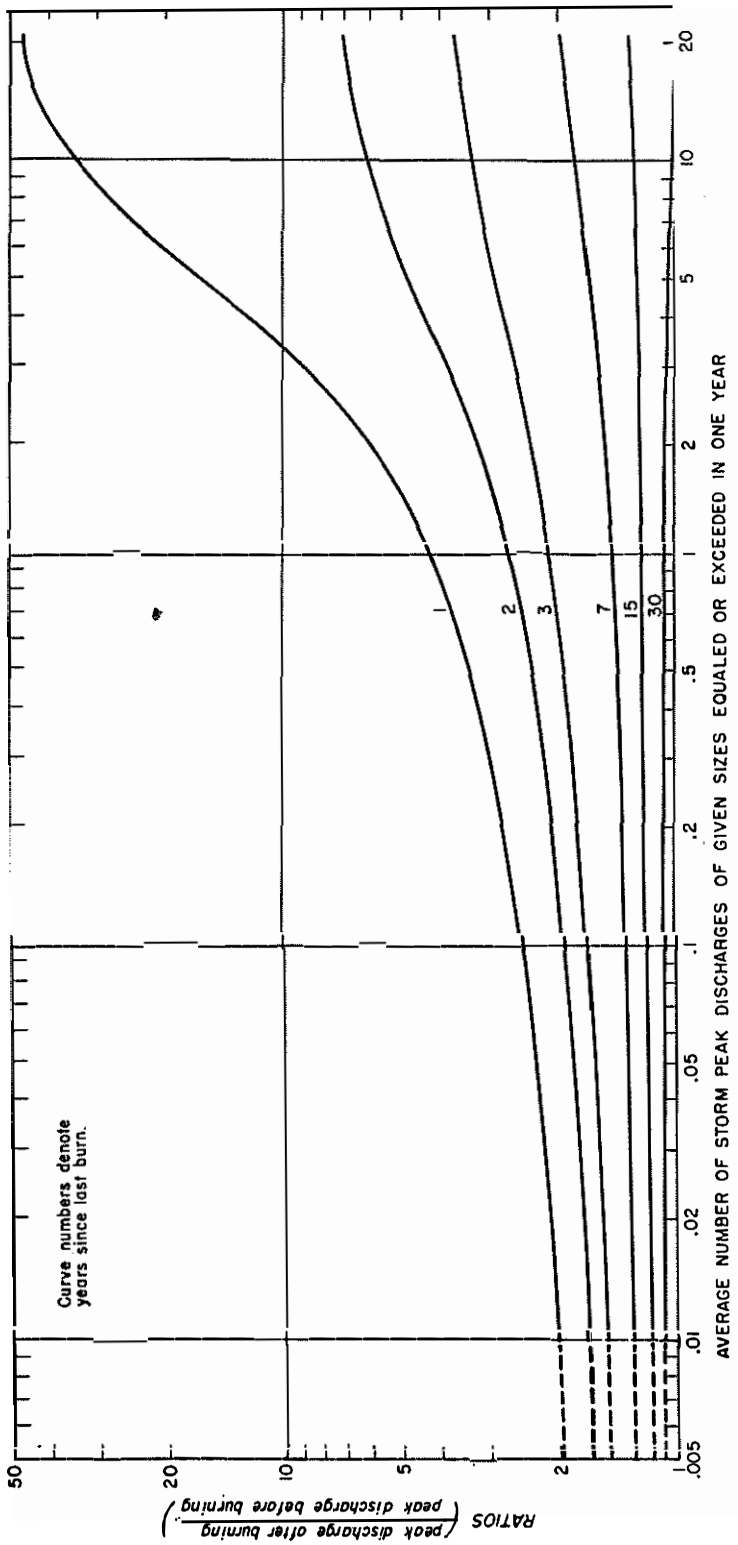


Figure 7.1 Average effect of fire on peak discharge by frequency classes and years following burning--Angeles storm zone.

moderately wet, and wet watersheds. Replication was obtained whenever possible in a storm-size group. Twenty-three storms were included.

The watersheds were selected to give as wide a representation in space as possible, including these watersheds for which there were adequate precipitation measurements. Twenty-seven watersheds were included in the peak-discharge-cause study.

A definition of variables and the regression equations giving the results of the study are given below:

$$\text{Log } Q = -3.245 + 1.084 \log A + .569 \log AP + 1.226 \log P_{24} + .785 \log P_1 + 3.084 \log T_m - \underline{0.991 \log C}$$

$$\text{Log } Q = 1.293 + 1.082 \log A + .474 \log AP + 1.870 \log P_{24} - \underline{0.852 \log C}$$

Q = Inst. peak flow (c. f. s.).
A = Drainage area (sq. mi).
AP = Antecedent ppt. (21 days--inches).
P_{24} = Max. daily rain (inches).
P_1 = Max. hour rain (inches).
T_m = Min. daily temp (^oF).
C = Cover density (o/o).
R = .954, N-127 = 29 areas x 23 storms.

An example of the equation for computing peak flows from a small watershed is given in table 7.2.

7.4 - Regional Hydrologic Analysis Using Multiple Regression. The meteorological, watershed, and management parameters were compiled from 21 watersheds and 126 flood events to develop indices of the major sources of variation in flood-peak discharge in eastern Oregon.[1] The result of the multiple regression analysis is expressed in the following equations:

$$\text{Log } Q'9 = -.2440 + 1.0681 \text{ Log } Q'8 + .0450 \text{ Log PSB} \quad \text{----------(1)}$$

$$\text{Log } Q'8 = 5.0735 + .2874 \text{ Log FR} + .5845 \text{ Log WR} - .8900 \text{ Log WT} + .1357 \text{ Log SR} - .2660 \text{ Log ST} - .8061 \text{ Log NS} - 2.2607 \text{ Log PH} + .9336 \text{ Log DA} \quad \text{----------(2),}$$

[1] Hobba, R. L., USDA, Columbia River Basin Agriculture Program 1954.

Table 7.2--Flood Peaks on City Creek Near Highlands, Calif.[1] (19.8 sq. mi.)

Recorded by U.S.G.S.			Calculated by Equation[1]							
Date	Peak Daily (cfs)		Burns		AP	P_{24}	P_1	C	K	Peak Q (40 yr.) (cfs)
			sq. mi.	%						
1920 3/22	443	190			5.2w	3.31			1.15	385
1921 3/14	1,320	393			1.0m	3.15			1.14	1160
1922 1/2	1,090	520	12.4	65.6	8.4w	4.65			1.13	960
1923 12/13	600	268			3.9w	4.01			2.18	275
1924 11/9	345	82			0.8d	1.39	0.28	26.4	1.77	195
1925 4/4	74	36			4.5w	1.38	0.22	33.0	1.61	45
1926 4/5	2,360	1,040			2.3m	8.49			1.51	1560
1927 2/16	1,930	1,200	2.0	10.6	2.4m	4.98			1.45	1330
1928 2/4	369	134			0.4d	2.55	0.60	43.0	1.50	245
1929 4/4	196	104			0.6m	2.88			1.41	140
1930 5/3	78	57			1.7+w	2.07			1.34	60
1931 4/26	146	56			1.8+w	2.43			1.28	115
1932 2/9	442	310			3.4+w	4.42			1.24	355
1933 1/29	62	32			8.0w	2.64			1.20	50
1934 1/1	374	245			11.3w	4.82			1.17	320
1935 1/9	166	84			7.0w	2.63			1.15	145
1936 2/2	580	142			0.1d	3.31			1.13	515
1937 2/6	1,040	374			2.9m	3.75			1.11	935
1938 3/2	6,900	1,990			4.8m	8.74	1.05	68.0	1.09	6330
1939 1/5	624	93			5.8m	2.01			1.14	550
1940 1/8	378	140			2.6m	4.40			1.11	340
1941 2/20	2,420	525	2.8	14.8	4.4m	4.66			1.09	2220
1942 12/10	172	63			2.1m	2.27	0.40	49.0	1.27	135
1943 1/23	2,300	716			3.0	11.5	1.07	61.5	1.22	1880
1944 2/22	1,030	318							1.18	870
1945 2/3	940	397							1.16	810

[1] $\log Q = 1.293 + 1.082 \log A + 1.870 \log P_{24} + .474 \log AP - .852 \log C$.

where:

Q'9 = peak discharge as computed with 9 variables--c.f.s.
Q'8 = peak discharge as computed with 8 variables--c.f.s.
PSB = watershed area which is burned, poorly stocked, or denuded--square miles.
FR = rainfall (October)--inches.
WR = winter rain (November through March)--inches.
WT = winter temperature (November through March)--mean temp. °F.
SR = spring rain (April--flood date)--inches.
ST = spring temperature (April--flood date)--mean temp. °F.
NS = component of watershed slope--percent.
PH = a watershed physiographic index--percent.
DA = watershed drainage area--square miles.

The October precipitation provides an index of ground-water condition. Precipitation during the winter is an index of moisture accumulated in the snow pack for release upon melting. The amount of moisture accumulated is affected by losses from the snow pack through melting and sublimation--temperatures during the accumulation period affect these losses with a resulting effect on flood runoff. Temperature and precipitation near the end of the normal snow season deserve special consideration. Basin characteristics affecting the variation in the magnitude of floods between watersheds consist of the drainage area; the poorly stocked burned and denuded area; the NS watershed slope component and the physiographic index which serves as an important factor in relation both to drainage composition and physiographic development of the drainage system.

Other indices could be used in addition to or in lieu of those developed. For example, fall streamflow might be used as an index to soil moisture. Also, if snow survey records of sufficient length and reliability were available, the water content of the snow could be used as an index of moisture available for release upon melting. Although there are many possible combinations of flood cause factors which could be used, the problem consists essentially in determining the way several major factors act together in their influence on flood magnitude. Of first concern is the selection of those factors, for which records are available for a particular area, and then to utilize them in a manner which will give significant results.

By analysis of variance and "t" tests the variables were significant in their effects on flood-peak discharge. The multiple correlation coefficient of equation (2) is .9006; and the standard error is .2320 (log units). This degree of correlation results from the fact that a great range of values has been considered in the analysis, and the degree of accuracy of the equation should be as near as the basic data will permit.

The equations and the partial regression coefficients are used to establish a hydrologic base against which the program effects can be com-

pared. The base usually used is the expected frequency of flood flows under present watershed conditions. This is obtained by:

1. Adjusting the existing records of discharges from a watershed as measures under the past variable watershed conditions to their expected values under a constant watershed condition (the present), using the partials from the cover variable in equation (1).

2. Extending the discharge record to a uniform long-term basis by:

a. Correlation of adjusted discharges between watersheds.

b. Correlation of adjusted discharges with recorded meteorological events by using the partials found for precipitation and temperature in equation (2). The assumption is made that events of the past, when adjusted and extended to a long-term basis, will be representative of expected events in the future (should the constant conditions be maintained).

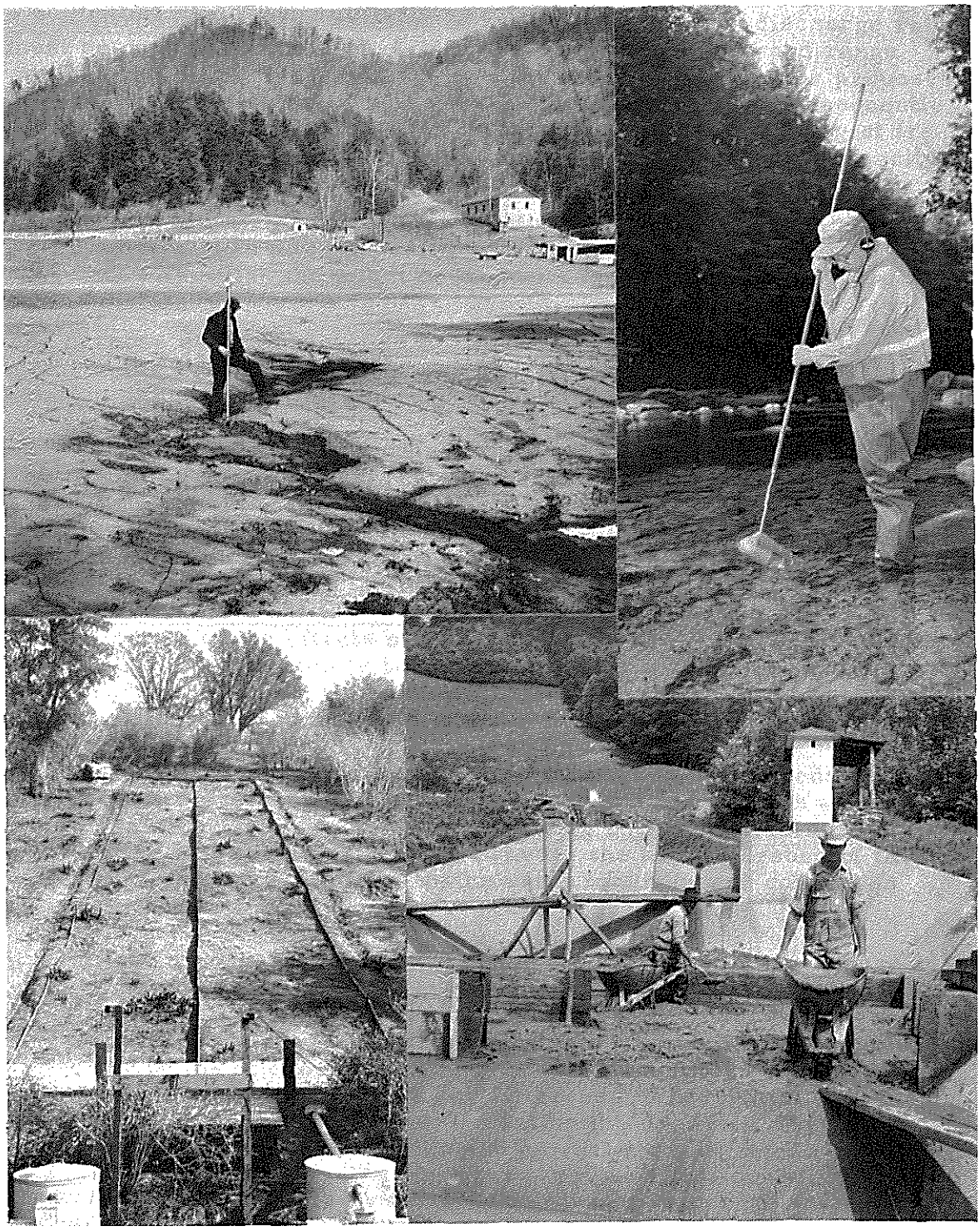
The adjusted and extended discharges representing present conditions are next converted to their expected magnitudes under future watershed conditions without and with a flood prevention program. This is done by:

1. Expressing the program in terms of the changes they (and time) will bring about in the cover parameter used in equation (1).

2. Using these changes, the effects on peak discharges are obtained from the equation.

SEDIMENTATION STUDIES

CHAP. 8



CHAPTER 8

8 - SEDIMENTATION STUDIES

8.1 - Introduction. The relation of sediment to stream-discharge rates must be considered in the hydrologic appraisal of forest and range watersheds. It involves evaluation of plant cover, present or proposed land use, and the effect of planned treatment measures. Consequently the interests of the land manager and the hydrologist or geologist frequently converge, especially when the sediment transporting capacity of streamflow must be considered.

The field of sedimentation is an extensive and highly technical subject. Nevertheless, it is often necessary that the manager of forest lands and rangelands appraise the effect of land management upon erosion and sedimentation.

The purpose of this chapter is to illustrate, by several examples, methods for evaluating sedimentation from watersheds, especially, in relation to changes in streamflow brought about by land use and fire.

More detailed instruction and procedures are described in FSH 3502. The results of related research studies conducted by the Forest and Range Experiment Stations of the Forest Service and the National Engineering Handbook, No. 3, "Sedimentation"--(SCS) will also provide valuable guidelines.

8.2 - Determination of Effects of Fire on Annual Erosion Rates.[1] Determination of the effects of fire upon erosion based on comparison of erosion rates of completely burned watersheds with those of unburned watersheds were studied in southern California. Details of the procedure are here illustrated by use of data from the Los Angeles storm zone.

Records of siltation from debris basins situated in watersheds completely burned over during the 1930's were used to establish average erosion rates by years from time of burning until return to normal. Siltation records from Santa Anita Canyon, the key watershed of the zone, were used to establish erosion rates for unburned conditions during the same time.

Streamflow records were not available for the burned watersheds. In order to establish the relation between erosion in these watersheds and peak discharge it was necessary to correlate the erosion with peak discharges of the unburned key watershed. This was accomplished by first computing ratios of erosion from the burned watersheds to erosion for corresponding periods from the key watershed. These ratios became practically constant in 10 years, indicating the establishment of relatively stable watershed conditions and normal erosion rates.

[1] Rowe, P. B.,; Storey, H. C.; Countryman, C. M.; "Hydrologic Analysis Used to Determine the Effect of Fire," California Forest and Range Experiment Station, 1954.

Data used in determining annual rates of normal erosion consisted of measurements of total siltation in reservoirs situated in watersheds with normal vegetation cover. Periods for which erosion records were available ranged from 1 to 15 years. Because of the short duration of the erosion records and because the siltation measurements were at irregular intervals including various numbers and types of storms, it was necessary to determine relations between the recorded peak discharges and corresponding erosion rates. These relations were then used to compute normal erosion rates of the individual watersheds on the basis of the normal peak-discharge frequencies.

The first step in determining relations between erosion and normal peak discharge was to prorate measured erosion to the individual discharges that produced it. To accomplish this, a representative cross section of the stream channel just upstream from the reservoir was selected for determining velocities by peak discharge sizes. The shape, cross-sectional dimensions, and average slope of this section were determined and a roughness coefficient was assumed. Velocities for all discharge peaks during the period of siltation measurements were determined and the total eroded material was distributed to individual peak discharges.

Regression analyses were run on the data collected in this southern California study to determine the relation of sedimentation of reservoirs to discharge and watershed conditions.[2] The results of these analyses were as follows:

14) $\text{Log } e = 3.490 + 0.896 \log q - 1.934 \log C$

$R = .949,$

$s = \pm .186,$

$n = 24$

t's: 13.668, - 2.249

15) $\text{Log } e = - 0.248 + 0.844 \log q + 0.505 \log Ach$

$R = .949,$

$s = \pm .86,$

$n = 23$

t's: 12.690, 2.122

[2] Anderson, H. W., "Flood Frequency and Sedimentation From Forest Watersheds," A. G. U., 1949.

16) Log e = 2.041 + 0.866 log. q - 1.236 log C + 0.370 log Ach

R = .953,

s = $\pm$ .184,

n = 23

t's: 12.788, -1.292, 1.437

e = annual sedimentation (ac-ft/sq./mi.)

q = maximum yearly discharge (c.f.s./sq. mi.)

C = forest cover density (percents)

Ach = area of channel (acres/sq. mi.)

8.3 - Relating Suspended Loads to Discharge and Cover Conditions. A study was made[3] of the San Juan River Watershed in Colorado, New Mexico, and Utah concerning the relationship of sediment carried by the river to cover conditions on the tributary lands.

Sediment samples of the runoff from the San Juan River near Bluff, Utah, have been taken by the U. S. Geological Survey since 1928. Daily discharge and sediment loads to 1941 published in Water Supply Paper 998 describes many floods where stages range up to 38,000 c.f.s. and sediments total as much as 11,450,000 tons per day. These flood periods were studied in detail to ascertain if the condition of the watershed within the storm area had any effect upon the amount of sediment transported by the stream.

Maps of the cover types and erosion on this watershed were prepared from a reconnaissance of the basin. Among other factors, the density of the vegetation and its potential were recorded by small subareas typing the area into over 100 parts. From observations of erosional activity a map had been prepared showing three degrees of sediment production areas. These two maps, vegetal density and sediment production, were used to relate the watershed conditions to the amount of sediment measured at the gage near the confluence of the stream with the Colorado River.

Isohyetal maps of daily rainfall during the flood periods were drawn from climatic summaries of the U. S. Weather Bureau. The area covered by significant rainfall of an inch or more was outlined and the runoff-producing area determined. Several gages on the main stream and many tributary stream gages were also used to determine which parts

[3] Rosa, J. M.; "Some Methods for Relating Sediment Production to Watershed Conditions," Intermountain Forest and Range Experiment Station, Research Paper #26, 1951.

of the basin contributed high-peak flows. These rainfall and runoff records indicate that most summer storms were not general over the whole basin, but were local floods originating from areas where cover conditions ranged from good forests to the poorest grass or shrubs.

The capacity of a stream for transporting sediment is an energy function and depends upon characteristics such as discharge, slope, channel shape, etc. The actual load, however, will depend upon a continuing supply of material available for transport, except for active channel cutting and unstable bed deposits. Therefore, at comparable stages of the stream the load should depend upon current erosional activity upon the watershed slopes and channels.

When streamflow is made up of such components as ground water, surface runoff, channel storage, etc., separation of flow types is necessary since not all the water has an equal opportunity to pick up sediment. With stable channels, clear water fed from ground-water storage carrys little sediment, since this water never flows over the surface to cause erosion.

In the study of the San Juan River Watershed, a normal sediment-discharge relation was first drawn for baseflow during rainless periods. High stages during spring runoff generally produced much less sediment than a comparable discharge from surface runoff during summer storms. Daily sediment loads were plotted against discharges during floods after subtracting both the estimated baseflow and the normal sediment for that stage, figure 8.1. These points for flood periods show considerable scatter indicating that the same amount of runoff does not always carry the same amount of sediment from a large watershed. These differences were averaged for the several daily points comprising one flood period and an average equation was fitted to the points of the form as follows:

$S = K Q^n$ where S = sediment load--tons/day

Q = mean discharge--c. f. s. /day (above baseflow)

n = power about 1.6

K = sediment coefficient ranging from 0.3 to 3.0.

An average value of the sediment coefficient for each flood period was determined by extending the average line thru each daily point back to the discharge origin of 1.0 c. f. s. These average coefficients were obtained for over 40 floods to be associated with watershed conditions.

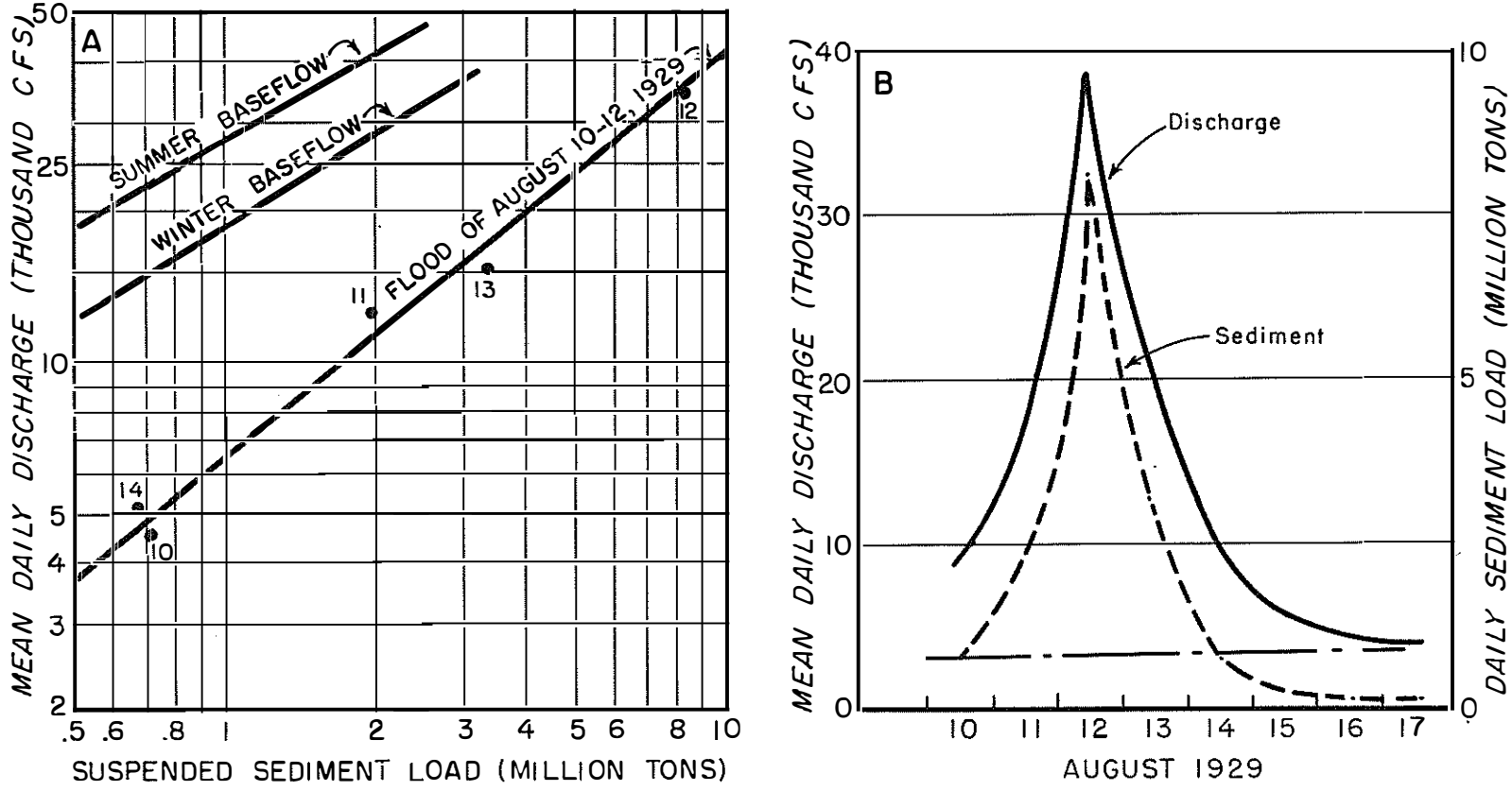


Figure 8.1 – Sediment-Discharge relations for flood of August 10–12, 1929, San Juan River

A correlation was made of coefficients observed by sediment sampling with sediment source areas as mapped in the field from observations of erosional activity. Three degrees of sediment production were mapped--low, medium, and high. The extent of each source area within each storm was measured. It was found by a trial and error process that reasonable correlation could be obtained for the 40 floods by using the following first estimates.

Sediment Source Areas:	Sediment Production Coefficients (tons/c.f.s. daily)
Low	0.33
Medium	1.33
High	3.00

The extent of the cover conditions within each storm area was determined by overlaying the isohyetal maps over the vegetation map. Floods where the sediment coefficient approached a high value of 3.0 were found to originate in the grasslands of the San Juan Plains. Coefficients as low as 0.3 were for storms which struck the timbered San Juan mountains. Examination of other storms limited to a few cover types enabled approximate values to be assigned good, fair, and poor conditions. By adjusting these estimates, a fair degree of correlation was arrived at for computed coefficients compared to the observed values from sediment sampling, figure 8.2. The coefficients listed below are considered to be reliable first approximations of the effect of vegetal cover conditions on the San Juan Watershed upon sediment production.

Sediment Production Coefficients

Cover type	Cover Conditions		
	Good	Fair	Poor
Conifer	0.3	0.5	-
Browse	0.3	0.5	-
Sagebrush	1.0	1.5	3.0
Juniper	1.5	2.5	4.0
Grass	1.0	2.5	5.0

Using the ratios thus established, it was then possible to compute the most probable rates that would result if the key watershed were burned. This computation was made as follows: the first year after the fire in one of the completely burned watersheds, erosion totaled about 75,000 cubic yards per square mile. The ratios described above indicate that the key watershed, if burned at the same time, would have had an

erosion rate for the same period of about 110,000 cubic yards per square mile. During this period of siltation six storms occurred with peak discharges that would produce erosion. The estimated erosion (110,000 cubic yards per square mile) was prorated to each of these peak discharges in the same manner as described for computing normal rates. The computed erosion rate allotted to each peak discharge was next plotted on logarithmic paper over the recorded peak discharge. Similar erosion rates computed by use of data form other burned watersheds was also used. A smooth curve was then fitted to these data. The same procedure was used for other years after burn and a series of curves showing the average relation between normal peak discharge and erosion by years after burn established. These curves are illustrated in figure 8.3.

Probable average annual erosion rates were computed for the key watershed for each year following a complete burn, using the same method as described for computing the normal rate. These rates were then plotted over time-in-years since burning, and irregularities between years eliminated by drawing a smooth curve through the plotted points. The average annual rates were read from this curve and plotted over the weighted normal peak discharge and annual erosion rate for individual watersheds was established by drawing a curve through the plotted point for each year after burn and parallel to the normal erosion rate curve for the south-slope watersheds from figure 8.4. This resulted in the series of curves shown in figure 8.5.

Estimates of the most probable annual erosion rates by years following fire for watersheds of the Los Angeles storm zone were read directly from the curves of figure 8.5. Entry to these curves was made through either the normal weighted peak discharge or normal annual erosion rate of the individual watershed. The estimated watershed erosion rates following burning were thus related directly to frequencies of normal peak discharge. As indicated in previous discussions, frequencies of peak discharge varied with storm zones. However, the relations between normal erosion rates and erosion rates following fire were reasonably constant from storm zone to storm zone. Thus these relations developed for the Los Angeles storm zone, figure 8.5, were also used to estimate the effects of fire on erosion rates in all zones.

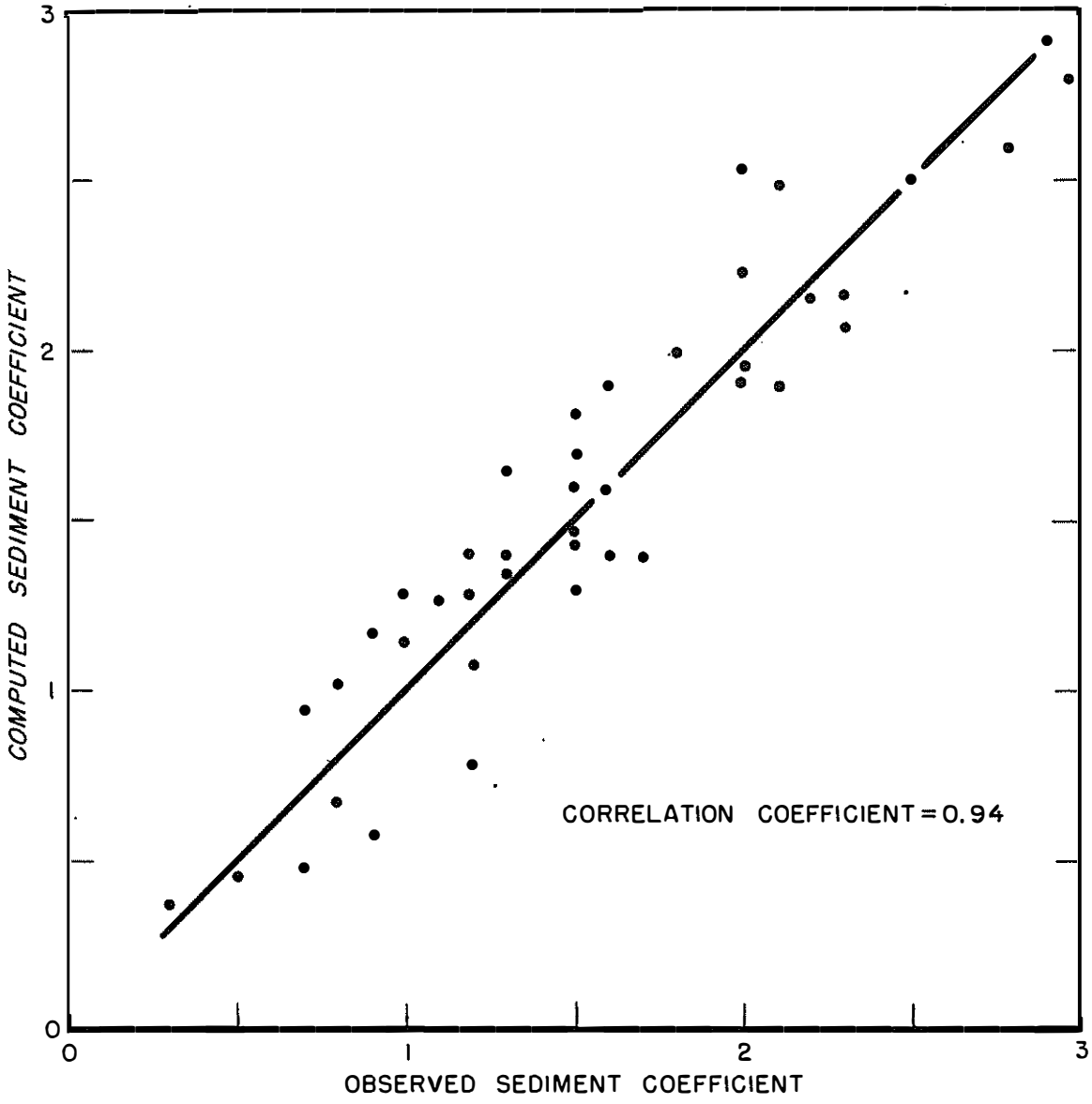


Figure 8.2 – Observed sediment coefficients obtained from suspended load stream sampling correlated with coefficients computed from plant cover conditions, San Juan River, 1928-41

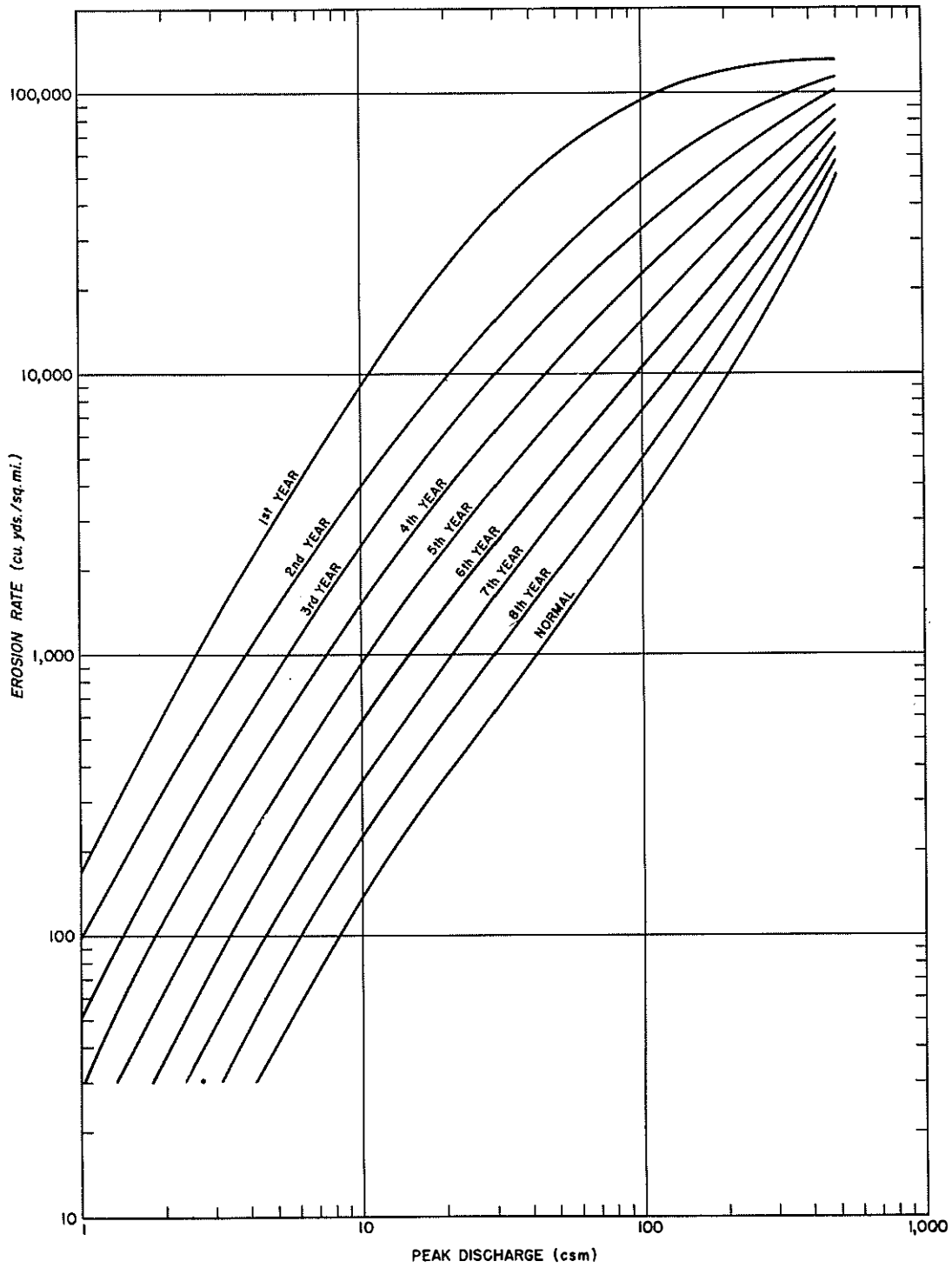


Figure 8.3 Relation of erosion rates to storm peak discharge following burning--Angeles storm zone.

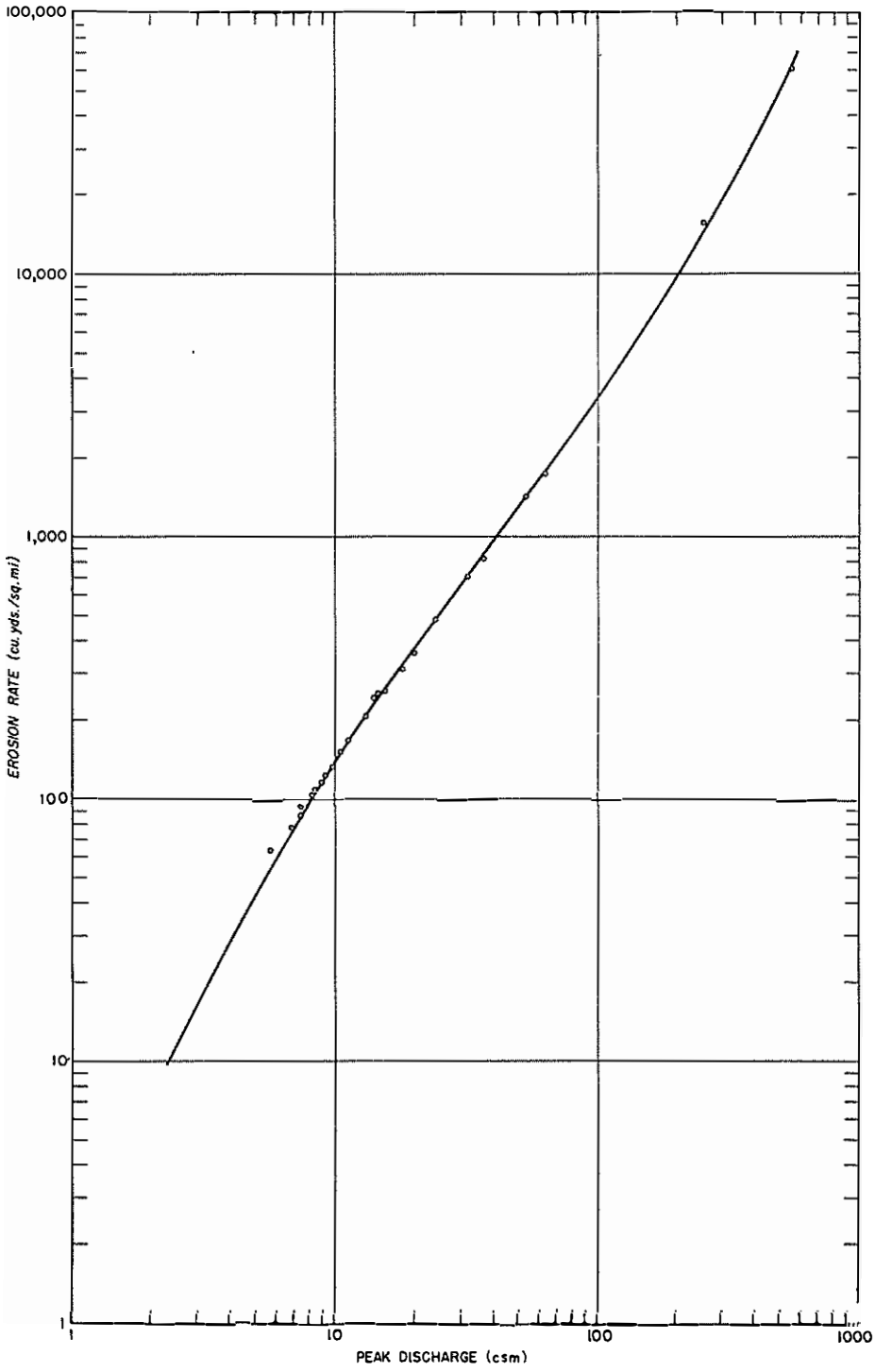


Figure 8.4 Relation of erosion rates to normal peak discharges -- Santa Anita Canyon, Angeles storm zone.

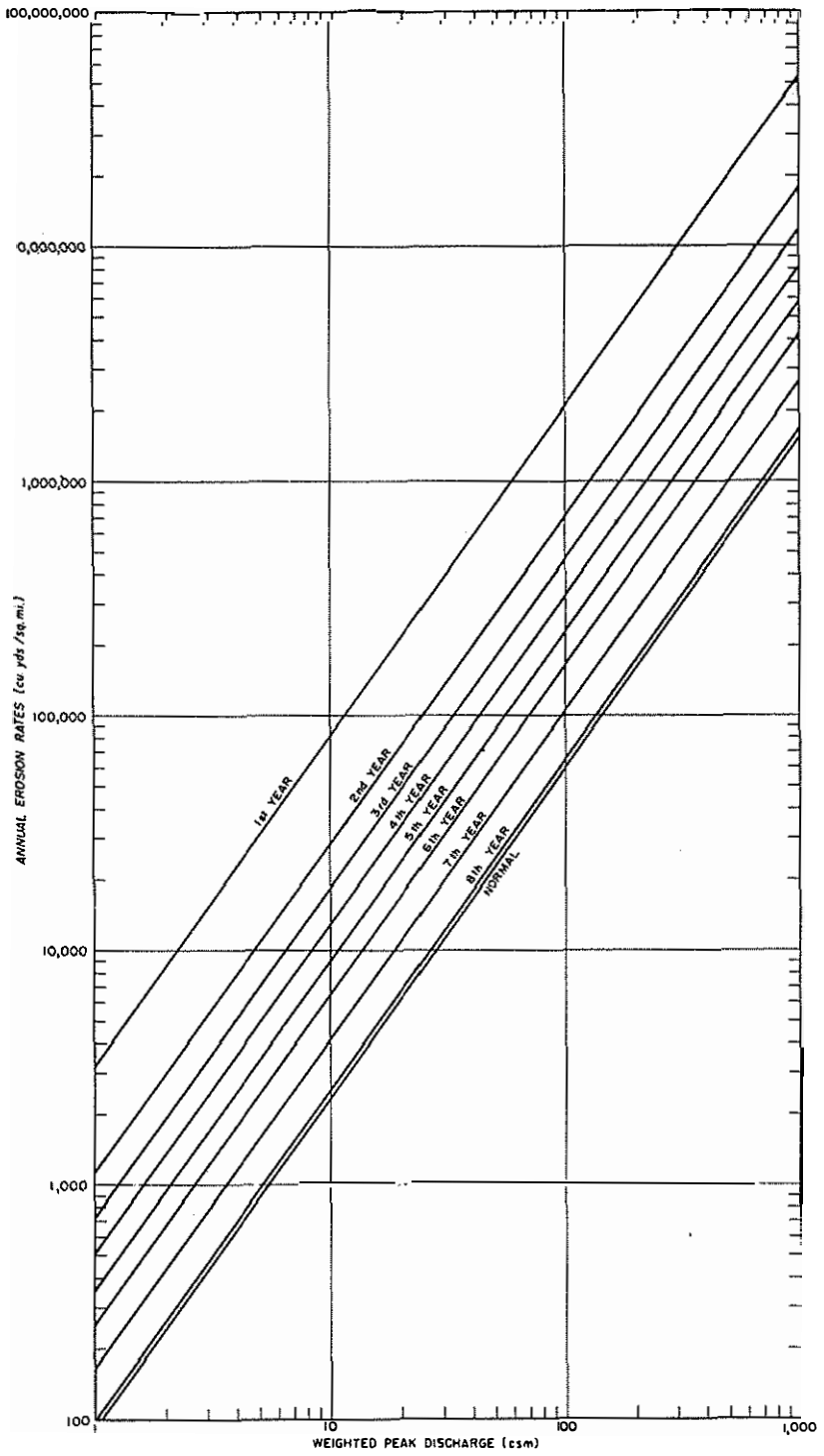
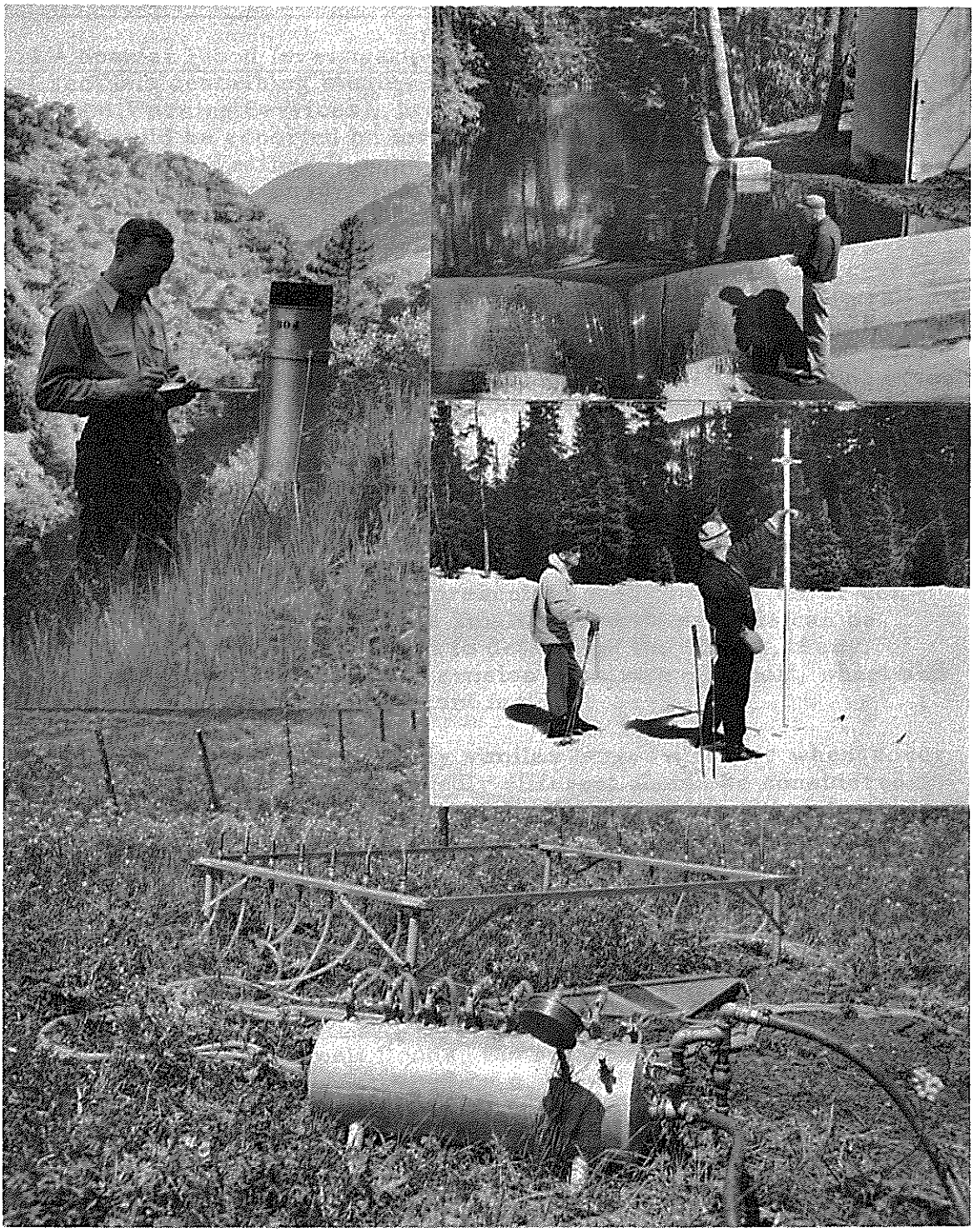


Figure 8.5 – Relation of annual erosion rates to weighted peak discharge following burning.

APPENDIX - HYDROLOGIC MEASUREMENTS

CHAP. 9



CHAPTER 9

9 - HYDROLOGIC MEASUREMENTS

9.1 - Special Flood Investigations. In reference to Forest Service manual sections describing studies in cooperation with other agencies (such as Flood Warning Services), hydrologic observations during current floods should be reported on forms similar to table 9.1, sheets 1-3. Generally, the Weather Bureau coordinates the field parties and reports the precipitation observations (see reference from Weather Bureau). The U. S. Geological Survey, Corps of Engineers, Bureau of Reclamation, or other agencies can be expected to collect most of the flood peaks and other runoff data, as suggested by sheet 3. However, there is a need for the Department of Agriculture to report watershed conditions contributing to the flood. Sheets 1-2 of table 9.1 are examples of forms for reporting cover, soil, and other watershed characteristics. These observations may also be coded on IBM cards, (see chapter 3, table 3.2, and chapter 4, table 4.3).

The field phases of these investigations logically divide into two steps. The first phase will be mostly a general reconnaissance of the area with particular attention to the watersheds. In addition to obtaining general information concerning flood conditions on specific tributaries, this will aid in locating pairs of smaller subtributaries or areas of otherwise comparable nature representing good and poor cover condition. In the second phase these small paired watersheds can be studied more closely in an effort to determine the effects, if any, of cover condition and accelerated erosion upon rate of runoff, sheet and gully erosion, and other significant factors.

General flood behavior of broadly similar larger streams when cover conditions are known to be markedly different should be considered particularly with respect to rates of discharge, sediment content, debris load, and channel cutting.

Attention should be given to channels with emphasis on their comparative ability to safely handle high discharges without excessive erosion. Where relatively clear runoff is leaving land surfaces and minor channels, the flood waters should be followed downstream to ascertain the source of sediments.

During studies of snowmelt floods, the snowline elevation on the various streams should be recorded on maps with respect to exposure and cover type at periodic intervals.

Hydrologic information, if available, should be collected and recorded with uniformity. All of the information called for cannot be obtained in all cases, but the forms will serve as a checklist.

Some attention should be given to generalized reports on location, nature, and relative extent of downstream damages, but available time should be largely devoted to study of what is happening on the land and in the stream channels.

9.2 - Severe Storm Surveys. So-called "bucket surveys" will, at times, be made after periods of unusually heavy precipitation. These surveys will be on a cooperative basis among the Weather Bureau, Corps of Engineers, Geological Survey, and Bureau of Reclamation. The Weather Bureau Area Hydrologic Engineer will represent the Bureau in the coordination with the other Federal agencies having inspectors in the field. Because of the need for starting "bucket surveys" as soon as possible after the end of a storm, Area Hydrologic Engineers will act on their own initiative. Section directors will cooperate with area hydrologic engineers by: (1) notifying the area hydrologic engineer immediately of any storm in their sections which they feel warrants investigation, and (2) promptly releasing hydroclimatic inspectors from routine office or field duties to the area hydrologic engineer when requested. These occasions will be infrequent.

The official precipitation gage network is reasonably adequate for general climatological purposes and for studies of general storms of average intensity. Experience has shown that it is not adequate to define precipitation patterns in and near the center of intense storms. The number of projects involving relatively small areas is constantly increasing. If adequate data are to be available for the design of these various projects, it will be necessary to accumulate data relative to the more intense storms as they occur. The only means of collecting these data is by supplemental storm survey made immediately after each storm occurs.

The collection of this supplemental data requires certain special techniques if the data obtained are to be considered reasonably reliable, and if they are to be in proper form for hydrometeorological analysis. The following material is a tentative guide for the collection of severe-storm data.

If two or more men are assigned to a survey, the area should be divided so that each man will have a specific area to investigate without overlapping the areas of the other men and without omitting any portion of the area. In general, it is advisable to begin the survey by making a profile through the storm area in two directions at approximately right angles to each other. If the storm area is elongated, one profile along the lengthwise axis of the storm is advisable.

Experience has proven that while a storm or the resulting flood is continuing, surveyors cannot get the attention of the public and are apt to get distorted and exaggerated reports. On the other hand, it is imperative that the survey begin immediately as soon as the storm has passed, since many of the containers which are potential sources of unofficial

measurements are likely to be emptied if the survey is delayed too long. There is also the possibility of more rain occurring.

If at all possible, the public in the area to be surveyed should be given advance notice of the expected survey. This may be accomplished by articles in the local press or by radio broadcasts. Daily weather broadcasts from Weather Bureau offices are a convenient outlet for such releases. The notices should emphasize the importance of the survey and urge anyone who believes he has a valuable record to notify the nearest Weather Bureau office or to contact the inspectors in some convenient manner. They should be told to leave the containers as they are until an inspector arrives. Persons keeping unofficial precipitation records are sometimes located. Such records are particularly valuable if they are made on a routine basis or after each storm as they are likely to be accurate.

The survey not only determines the amount and location of the storm center, but also defines the outer borders. Therefore, the survey will extend into areas of relatively small amounts of precipitation. The more measurements obtained the better, as it is then possible to define accurately the areal extent of the most intense rainfall and a large number of corroborating reports naturally lend more credence to the data than several isolated observations.

The Precipitation Survey form designed by the Weather Bureau for use in storm surveys is illustrated in table 9.2. It is important that all blank spaces be filled in.

The location of sampling sites can be resolved largely into a house-to-house canvass throughout the storm area. In urban areas, the press and radio publicity is a necessity because of the relatively few containers left out in a position where they may catch rainfall. In rural areas, the problem is a little easier because most farms have some type of open container lying about. The urban people are usually interested in effects of a storm on their own operations and are, consequently, usually a little more observant in regard to the weather. Upon his arrival, the inspector should contact local city and town officials, postmasters, and local newspapers. They may be able to furnish some leads as to persons who are likely to have the data needed. In sparsely settled areas, the general store or garage is the likely place to make contacts.

The inspector should introduce himself to each person to be interviewed. His manner should be tactful and friendly, and he should give a short explanation of what he is attempting to do so that he may obtain the full confidence of the person being interviewed. While the inspector does not have time to waste, he must not rush the interview. Even though the person being interviewed cannot provide information on depth of rainfall, as much information as possible should be obtained, concerning time of occurrence of storm, occurrence of thunder and lightning,

wind direction, and direction of travel of the storm, and any other data which may be helpful in locating other sources of data.

In general, indirect questioning is preferred. The direct question, "Was the container empty before the storm?" will frequently be answered by an equally direct answer, "Yes." Instead, inquire as to the use of the container, when it was last used, and whether any rain had occurred since it was put out prior to the storm being surveyed. These and similar questions enable the inspector to arrive at a reasonable opinion of the condition of the container prior to the storm. If the container has not been disturbed since the storm, the measurement is simple. The dimensions of the container are taken and sketched. The volume of water in the container should be measured carefully. A standard one-quart and one-cup measure are well suited for this. Dip or pour out the water, being careful to have the measure filled to the brim and not to lose any water. Then knowing the volume of water caught and the area of the opening at the top of the container, the actual depth of rainfall may be easily computed.

If the container has been emptied or rain has occurred since the storm, it will be necessary to obtain an estimate from the observer as to the depth of the water at the end of the storm. This can best be accomplished if the inspector will put water into the container until it is filled to the level which the observer indicates to be the proper depth. The water should be poured at a fairly rapid and constant rate in order that changes in the rate at which the water is poured do not influence the observer's decision.

After measuring water in container and determining its measurements, a careful study of its exposure should be made. Any evidence that water may have been caught from sources other than natural should be noted and record considered doubtful. Particular note should be made of trees, buildings, etc., which might have a sheltering effect on the container. The ideal exposure will correspond to that desired for official gages.

In addition to the reports of interviews, the inspector should take careful note of other data which may be helpful in the storm survey.

Extent of erosion, damage to trees, puddles standing in fields and damage along stream beds, and similar factors will help define the limits of excessive rainfall. This information can be sketched on a map of the area--the inspector should have suitable large-scale maps before starting on the survey. Photographs of each container and its exposure, general photos of the storm area, newspaper clippings, and other supplementary materials should be submitted with the inspector's report. The inspector's evaluation of each sample is very important. He can see the container in which the sample was caught;

he talks with the person supplying the data, and is therefore in a far better position to judge the reliability of the information than the analyst studying the data. The inspector should be very liberal in entering remarks when completing his report of each interview.

9.3 - Stream Gaging. Stream gaging is the measurement of the rate of streamflow past a selected point in a stream channel at periodic time intervals over a period of years, for the purpose of determining extremes and average rates and volumes of flow.

9.31 - Need for Stream Gaging Data. Streamflow records are of importance to the Forest Service for two reasons:

First, the rate and volume of streamflow express the combined influence of all of the climatic and physical characteristics of a watershed. Changes in the quality and rate of streamflow reflect the impact of our land-management activities upon the water-handling capabilities of a watershed. Streamflow is the only part of the hydrologic cycle in which water is so confined as to make possible a reasonably accurate measurement of the quantities involved.

Second, a long-time record of streamflow provides a means of predicting future flows which is important in the design of culverts, bridges, channel changes, dam spillways, and other water-handling structures.

9.32 - Present Status of Stream Gaging. The U. S. Geological Survey is responsible for the measurement of streamflow in the United States. There are approximately 6500 USGS permanent stream gages in the U. S. Records of discharge for all of these stations are published annually by the USGS in booklet form called "Water Supply Papers." The papers are divided into 18 parts covering the major drainages or portions of drainages in the United States.

Some of the gages have continuous records for more than 50 years. The records for both recording and staff gages are published in the form of average daily discharges for each day of the water year which runs from October 1 to September 30. The more recent records also show an estimate of the maximum discharge during the year. Copies of the recording gage charts can be used with the rating curves to determine the discharge at any instant of time.

The most serious defect in the available stream-gaging data, from the land management standpoint, is the almost complete lack of records on small drainage areas. For the purpose of analyzing the effect of logging activities on a sale area, or for estimating the required capacity of a road culvert, the existing USGS streamflow records are of very limited value.

Table 9.1 (Sheet 1)

FLOOD INVESTIGATION FORM

Date of investigation _____ Party _____

Location _____

_____ Basin _____ River _____ Drainage

State _____ County _____ T. _____ R. _____ Sec. ____

	Sub-area A	Sub-area B	Sub-area C	Sub-area D	Sub-area E	Sub-area F
Watershed condition						
Land use (type)						
Disturbance (degree)						
Topography						
Map No.						
Photo. No.						
Area (acres)						
" (% sampled)						
Elevation, max.						
" min.						
Land form						
Slope (av. %)						
Aspect (general)						
Soils						
Parent material						
Soil texture (surface)						
" " (subsoil)						
Soil depth (to bedrock)						
" " (effective)						
Erosion						
Past erosion						
Present sheet erosion						
" gully "						
Bank cutting						
Surface cover						
Rock outcrop %						
Talus %						
Rock pavement %						
Bare ground %						
Effective cover % (veg. & litter)						
Plant cover						
Cover type						
High forest density %						
Shrub density %						
Per. grass-forbs, dens. %						
Ann. " -weed, dens. %						
Litter density %						

Table 9.1 (Sheet 2)

	Sub-area A	Sub-area B	Sub-areaC	Sub-areaD	Sub-area E	Sub-area F
Climatic conditions						
Snowline elevation -before						
-after						
Snow depth (or w/c) -before						
-after						
Frost -type						
-depth						
Soil moisture-before						
-after						
Rainfall (flood per.)						
	Section A	**Section B**	**Section C**	**Section D**	**Section E**	**Section F**
High water computation						
Channel gradient (%)						
" roughness (N)						
Flood depth (ft.)						
Cross section (sq. ft.)						
Velocity (ft./sec.)						
Drainage (sq. mi.)						
Flood peak (c.f.s.)						
Unit discharge (c.f.s./sq. mi.)						
Overland flow						
Subsurface flow						
Ground water flow						
Sedimentation						
On site (A. feet)						
Downstream "						
Channel photo nos.						
Turbidity (p.p.m.)						
Bedload %						
Floating debris (kind)						
" " (amount)						

Table 9.1 (Sheet 3)

FLOOD INVESTIGATIONS
(Supplemental - hydrologic data)

Location _____ Party _____

Station location	Station A	Station B	Station C	Station D	Station E	Station F
	OFFICIAL WEATHER OBSERVATIONS					
Elevation						
Temp. (max. daily)						
" (cumulative)						
Precip. (max. daily)						
" (fall)						
" (winter)						
Snow pack (w/c before)						
" (w/c after)						
Wind (max. daily)						
	OFFICIAL RUNOFF OBSERVATIONS					
Gage location						
" elevation						
" type						
Length of record						
Flow (before) c. f. s.						
" (peak) c. f. s.						
Flood volume (A. ft.)						
Max. record (c.f.s.)						
Area above gage (sq. mi.)						

Remarks: (Unofficial observations)

TABLE 9.2

Field Serial No. Office Serial No.

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

Precipitation Survey

Observer:
Address:
Direction and distance from nearest Post Office:
Road directions:

Sec. Twp. Range Lat. Long. Elev.

Description and dimensions of container:

Exposure (Good, fair, poor. If fair or poor, give reasons.):

Was container empty before storm?

Standard Time Used:

Began		Ended		Observation		Measured Depth	*
Date	Time	Date	Time	Date	Time		

* If container not straight-sided, the inspector or Regional Office will enter equivalent depth.

Method of measurement:

Remarks: (Time, estimate of overflow. Time of heaviest rain. Lightning, thunder, windshifts. Comparative depths at adjoining locations. Any information helpful in evaluating reliability and representativeness of observation.)

Date _____ Signed _____

Furnish copy of this report to Hydrometeorological Section, U. S. Weather Bureau and to Division Office, Army Engineers.

The USGS is not unaware of the need for records on small streams. However, their financing has never permitted them to expand to this field except on a cooperative basis and such cooperative projects have been rare and limited in scope. At this time we can foresee no possibility of financing a cooperative project of sufficient scope to provide us with the data we need. Nor can we look to our research organization for this information, for such a program is not within the scope of their financing or their responsibilities. We do not have sufficient personnel of our own who can devote full time to such a project. We do, however, have a large number of people over a large area who can, if necessary, spend a limited amount of time on such a project. No other organization in the country is as well adapted to make a limited number of discharge measurements on a great many small streams with such a relatively small expenditure of time and money.

9.33 - Computation of Discharge. The rate of streamflow is the product of the cross-sectional area of the channel and the velocity of flow. The rate of flow is commonly expressed as cubic feet per second (c.f.s.), the product of the cross-sectional area in square feet and the velocity in feet per second.

1. Velocity Measurement. The velocity varies both vertically and horizontally in the channel cross section and the average velocity must be determined. In a large stream it is customary to divide the cross section into segments and determine the average velocity for each. The velocity is lowest along the stream bottom and sides, because of friction, and highest on the surface in midstream. There are three common methods of measuring velocity of flow:

a. Float Method. One method is to put a float in the middle of the stream and determine the time it takes to travel a measured distance. The average velocity varies from about 0.80 to 0.95 of this surface velocity depending on the size and character of the stream.

b. Velocity Head Rod Method. Another method is to measure the velocity head with a velocity head rod and compute the velocity by the formula $v = \sqrt{2gh}$. (Where v = velocity in ft./sec.; g = 32.2 ft./sec./sec., the acceleration of gravity; and h = the velocity head in ft.) This method gives the average velocity vertically at the point of measurement. Several measurements must be taken to get an average velocity across the entire channel. This method is limited to streams which can be waded.

c. Current Meter Method. The third method is to measure velocity with a current meter. This instrument has a wheel which is turned by the force of the water and the number of revolutions per minute is counted and converted to velocity by means of a rating table for the meter. This method gives the velocity at the point of measurement. To get the average velocity vertically through a cross section, the measurement is taken at 0.6 of the

water depth at which point the velocity approximates the average. Sometimes two measurements are taken at 0.2 and 0.8 of the depth and these are averaged. As with the velocity head rod, several measurements must be taken to get an average velocity across the entire channel. This method is in common usage on larger streams. A miniature or pygmy current meter is sometimes used on small streams.

The velocity head rod and the current meter give results of comparable accuracy. For streams which can be waded, the velocity head rod is preferable because it is cheaper, easier to use, and automatically averages the velocity in the vertical line of the measurement, thereby eliminating one source of error.

2. Cross-Sectional Area Measurement

a. Open Channels. The area of the channel cross section is commonly determined by averaging the depths measured with the velocity head rod or current meter rope, at each of the points where velocity is measured. The area is computed by multiplying the measured channel width by the average depth. The channel cross-sectional area may be determined with more refinement by making a stream-bottom profile by ordinary surveying methods.

The accuracy of the discharge measurement depends to a large degree upon the accuracy to which the cross-sectional area is determined and the stability of the cross section.

Measurements of flow in a natural channel are subject to inaccuracies caused by changes in the channel cross section. Some channels are subject to constant change and are, therefore, difficult to gage accurately. At high flows much of the stream-bottom material may go into suspension and move down stream. The amount of this so called bed-load flow is difficult to measure and the actual water depth is very difficult to determine. Such a channel can be measured more accurately by means of a weir which provides a controlled channel cross section.

b. Weirs. A weir is essentially a dam with a notched opening over which all of the water flows. Weirs are commonly constructed of concrete, metal, or wood. The weir notches may be of various shapes depending on the volume of flow and the accuracy desired. Common shapes are flat bottomed with vertical sides for greatest capacity, and V-shaped for greater accuracy at low flows.

In either case, the velocity measurement can be eliminated since the discharge can be computed by formula if the dimensions of the weir and the depth of flow are known. This method is expensive and is resorted to only when great accuracy is desired and, even then, is limited to fairly small streams.

c. Culverts. Discharge can also be measured quite accurately through culverts. If the size and slope of the culvert and the depth of water above (and below when the outlet is submerged) is known, the discharge can be computed by formula.

9.34 - Stage-Discharge Relationship. A curvilinear relationship exists between depth of water, or stage, and discharge. This relationship is utilized in all permanent stream-gaging installations.

This relationship can be established over a period of time by computing the discharge at various stages by one of the methods described above, and plotting the resulting values with discharge as the abscissa and stage as the ordinate. A curve drawn through these plotted points is called a rating curve.

When this rating curve has been established, the discharge may be determined at any future time by measuring the stage and reading the discharge from the rating curve.

9.35 - Types and Capabilities of Stream Gages. A stream gage is a device to facilitate the measurement of stage, which is then converted to discharge by means of the rating curve. Gages are of three basic types; the crest gage, the staff gage, and the recording gage. Differences in their inherent accuracy are negligible. They differ primarily in the frequency of measurement and hence in the type of information they can furnish. Variations in the cost of the gage, cost of installation, and the amount of supervision required for their operation are factors to be considered in selecting the most appropriate type for a given purpose.

1. Crest Gage. The crest gage records the maximum stage occurring between observations. It can be read as often as desired, but is usually used to obtain a measurement of maximum annual discharge and any unusual flood peaks which may occur. Variations of this type of gage may be used to record minimum flow. This type of gage can be produced for less than $10. Installation requires several hours of labor. The time required for observation and supervision is relatively small, consisting of reading and resetting the gage after the spring runoff each year and after any unusual floods.

2. Staff Gage. The staff gage is the cheapest of the three types to manufacture and install. It can be manufactured for less than $5 and installed in a few minutes. It consists of a graduated staff mounted on a tree, post, or bridge abutment. The cost of operation and supervision is highest of the three types. The gage does not record any measurements. It is read daily or twice daily. These readings provide a basis for computing annual yield. The gage will not give annual maximum or minimum flows except by observation at the time of the flow. Its use is limited to locations which are readily accessible to the operator.

3. Recording Gage. The recording gage records on paper a continuous record of stage. This record provides not only the magnitude but the time of occurrence of the maximum and minimum flows and all flood peaks. It provides the data required to compute the annual yield, and other useful hydrologic information about the watershed. The time required for operation and supervision of the gage is less than that required for the staff gage. Gages will record automatically from 1 week to 1 month without servicing. The time required to analyze the record, however, may be considerable, depending on the type and accuracy of data desired. The cost of a recording gage and installation may run from $1500 to $3000.

9.36 - Gaging Program. To obtain an inventory of streamflow from national forest watersheds in the most efficient and economical manner requires some analysis of the problem. Because of the many small streams involved, even the most intensive gaging program can be no more than a sampling of the universe of data. The first step, therefore, must be to stratify the universe into areas of reasonably similar runoff characteristics on the basis of available data. Because the complexity of the problem and the kind and quantity of available data varies throughout the nation, the method of stratification must be developed on a regional basis. The data used as a basis for such a stratification may include rainfall or snow course records, soil surveys, timber inventories, isohyetal or topographic maps, and existing streamflow records. It is conceivable that crest gage installations can be of sufficient intensity to comprise a random sampling of a stratified sample or even of the entire universe. We can never hope, however, that the more expensive recording gage installations can ever be used on more than a selective sampling basis.

It is important, therefore, that such recording gage sites be carefully selected with perhaps a maximum of one gage within each stratification of the universe to be sampled.

9.37 - Gage Installations. Criteria for selecting locations and installing the gages are as follows:

1. Crest-Stage Gages. These gages will, by themselves, provide useful data, and this data obtained prior to establishing the location of recording gages will be of great value in the determination of proper locations for the recording gages. Crest-stage gages should be installed on streams which have no artificial storage in the watershed. They should be located on streams which drain more than 1 but less than 20 square miles. It will be desirable at this stage of the program to work toward reasonable uniform distribution of gages throughout the forest area. One or two streams on each forest should eventually have three gages in series at different drainage areas. The ideal location for the gage is on a straight uniform reach of the stream at a point where maximum-flood flow will be confined to a definite channel area. The gage should be mounted on the downstream side of a tree to protect it from debris. It should be referenced to a permanent benchmark.

2. Staff Gages. Installation of staff gages will be limited to points adjacent to ranger stations which can be conveniently observed once or twice a day. The staff gage will be mounted on a tree, post, or bridge abutment. It may be painted on a concrete abutment. The zero of the gage should be low enough to give a plus reading at low water. The gage should be referenced to a permanent benchmark.

3. Recording Gages. Recording gages should not be installed until the stratification of similar runoff areas had been made and the proper locations have been established for the entire system of recording gages.

9.38 - Records and Reports. Standard forms for recording measurements and methods for collecting and analyzing the data should be established in each region as an initial step in the stream-gaging program.

Regions may elect to incorporate as part of the program a sampling of water turbidity or sediment yield. Such measurements will in most cases have to be limited to a sample during the spring runoff period and during unusual flood peaks during the year.

9.4 - Work Plan for Hydrologic Study

9.41 - Object. To determine the influence of physiography, soil, land use, vegetation, and meteorology on the character of water yield and extent of soil erosion and flood flows from mountainous watersheds. Further, to determine water yields and how floods and erosion from mountain watersheds can be controlled most effectively by manipulating vegetation and land use.

9.42 - Scope. A study is designed to provide information on watershed problems of a specific national forest. Particular emphasis will be placed on water yield with consideration of flood and erosion control problems. An effort will be made to determine the influence that topography, soil, vegetation, land use, drainage pattern, and storm characteristics have upon runoff and erosion. Selected drainage units in the watershed will be studied intensively. These drainages may be from a few to several thousand acres in size.

The study will begin by determining accurately the physical and hydrologic characteristics of the drainage units, after which the land will be treated and the effects of the treatment determined. The study will involve the installation and operation of weather stations, rain gages, stream and silt gaging stations; measurement of climate, precipitation, discharge and silt movement, and environmental factors such as slope, soil, plant density, land use, and infiltration; and the compilation, analysis, interpretation, and publication of data.

The area included in the study will be typical of the major water yield or flood and silt contributing drainages of the watershed. The land treatment proposed will be aimed primarily at water yield including flood prevention and will include modification of land use, improvement of vegetation density and composition, and perhaps installation of minor structures such as contour furrows or trenches and gully stabilization.

9.43 - Justification. The State engineer's offices, water conservation boards, irrigation companies, and other water interests have become quite concerned over the effects that vegetation and detention structures, including contour furrows and terraces, will have upon water yields and water rights. It is desirable, therefore, that hydrologic studies be established and that selected drainages be treated to determine the effects that land-use adjustments and minor structures will have upon runoff. A long-time hydrologic study of these watersheds will furnish sufficient basic information so that the Forest Service and others will be in a position to answer pertinent questions concerning water yields.

The drainage units proposed for study should be of a size small enough to permit unified treatment and should show differences in runoff characteristics resulting from the anticipated remedial program. Choice of the watershed for the hydrologic study might be based upon the typical water yield or serious nature of its flood problem, the typical character of drainage formation, vegetation, land use and other drainage area characteristics, and the existence of tributary drainage areas of size, pattern, and character desirable for study.

9.44 - Basic Investigations. The basic investigations to be conducted on the study area are divided into two groups: those dealing with the physical factors of the area such as topography, geology, soil and erosion, and vegetation and land use; and those dealing with the hydrologic factors such as climate, precipitation, infiltration, streamflow, and silt movement. All of these factors will be studied in order to determine their relation to water yield or accelerated erosion and flood flows. During the course of the study additional factors may be found which have an important bearing on erosion and waterflow and will require intensive study.

9.45 - Topography and Shape. The purpose of this phase of the general study is to determine the size, shape, and topography of each of the drainage units selected for intensive investigation. Sufficient control points will be located to tie in existing or special air photographs of the drainages. Base maps will be prepared on a scale of 4 inches to 1 mile, with a contour interval of 50 feet determined by stereo-plotters.

9.46 - Soil and Erosion. Soil types and erosion conditions will be delineated on each drainage unit in order to provide an appraisal of

soil factors--such as erodibility, depth and permeability--which may influence runoff and silt movement. Soil samples will be taken for laboratory determination of percolation, detention and retention storage, etc.

Delineation of soil and erosion conditions will be made by systematic inspection of each drainage unit. This will require two technical men (soil surveyor and range examiner) and they will together examine the different conditions of soil, erosion, and vegetation within each drainage unit, observing surface conditions indicative of the degree of erosion. The examination of soil, erosion, and vegetation conditions will be made on selected sample plots. These plots will be established by a grid system of the entire study area. Plots will be established on areas where surface indications denote changes in types of soil, erosion, and vegetation.

9.47 - Vegetation and Land Use. Existing vegetation and land use will be delineated; changes in these factors resulting from nautral or induced causes will be observed; and the effect of these factors on infiltration, runoff, waterflow retardation, and erosion will be interpreted.

The study will delineate vegetation type boundaries. The vegetation types then will be subdivided into the condition-class areas established by the study of soil and erosion previously described. This subdivision will be accomplished by preparing overlay maps of vegetation and condition-class areas and designating within the types the areas of different condition classes.

The density of the vegetation will be determined. Sufficient plots will be secured in each condition class within each type to provide a statistically sound sample. The location of all plots on which density is observed will be recorded on base maps for recurrent study. Following the initial survey, recurrent measurements of the density and composition of the vegetation will be made.

The growth and development of individual plants will be studied to differentiate between natural (climatic) and induced (protection, grazing control, structural treatment, etc.) changes in plant cover. Measurements of key species (to be determined after field study) will be made at intervals beginning in spring and continuing until the vegetation becomes dormant in the fall. Study plants will be selected inside fenced enclosures.

9.48 - Precipitation and Streamflow. The purpose of this phase of the hydrologic study is to determine rainfall characteristics, including the amount, intensity, magnitude, and frequency of storms and their effects on water yields and peak discharge.

Involved in this investigation will be the installation, maintenance, and operation of a network of rain gages and snow measurements within the study area, and the collection, compilation, and interpretation of the data.

The rain gages will be installed in accordance with instructions in the U. S. Weather Bureau Handbook and specifications determined at the Forest and Range Experiment Stations.

After the precipitation-gaging system has been installed, its operation and maintenance during the field season will require weekly attention and general inspection after every major storm. During the winter season it will be necessary to check accessible monthly storage gages and to sample the snow-water content. This job can be done concurrently with stream-gaging station work.

The streamflow investigations will determine runoff and streamflow characteristics, including the volume, rate, and duration of discharges, total yields and types of flows; and the effect of these factors on floods, streambank erosion, and movement of silt and debris. Further, the influence of vegetation, land-use adjustments and upstream engineering work upon runoff and streamflow will be determined.

Involved in this study will be arrangements for the installation, maintenance, and operation of stream-gaging stations (located at the mouths of the drainage units selected for investigation) and the collection and compilation of the data (U.S.G.S.). After the stream-gaging stations have been installed they will require rating. Stage-discharge relations that have been determined by laboratory studies will be checked in the field with current meter at selected gaging stations (U.S.G.S.). Discharge data collected on the study area will be compiled on approved hydrologic forms presented in the Forest Experiment Station's Technical Notes.

9.49 - Treatment of Study Area. Measurement of all desired factors under existing watershed conditions on untreated areas will be continued for a period long enough to establish trends (more than 5 years). Treatment of selected comparable areas for water yield, flood prevention, or erosion control will be accomplished. Observations will then be made of the influence of such treatment on water yields, silt movement, and peak discharges as well as on soil erosion, plant cover, and land-use conditions.

The exact nature of the operations program will be determined by means of a detailed survey of the watershed. Some possible treatments that might be considered in an operations program are listed for the drainage units in table 9.3.

Table 9.3.--Possible Treatment for Watershed Improvements

Drainage	Type of Control Measure
Total	Grazing control, fire protection, contour furrows and trenches, range reseeding, road drainage, gully stabilization, cover type conversions.
Small #1	Grazing control, protection.
" #2	Cover type conversions (aspen, brush, etc.).
" #3	Grazing control, protection, contours, road drainage, etc.
" #4	Fire protection (untreated check area).
Large #1	Grazing control, protection, contour trenches, reseeding, etc.
" #2	Cover type conversions (aspen, brush, etc.).
" #3	Timber harvesting methods.
" #4	Check area (adjacent untreated forested watershed)
" #5	Check area (adjacent untreated range watershed).
" #6	Grazing control, protection.

Analysis and Interpretation of Results. In the foregoing section "Basic Investigations," the study procedure has been presented. In addition, certain methods for the compilation and analysis of data were discussed. For clarification, however, it is worthwhile to summarize the methods of analysis and indicate how the data will be correlated by pointing up the relation of the individual investigations to the entire study.

All data obtained throughout the study will be promptly compiled on suitable charts, maps, and forms. The exact specifications for these can be developed only as the study progresses. The guiding feature in preparation of final records will be to secure a compilation readily usable for scientific analysis and interpretation, and convenient for filing and consultation.

The compilation of hydrologic data will follow procedures similar to that suggested in Technical Notes of the Forest Experiment Stations.

This procedure employs a series of forms to compile various phases of the hydrologic data and presents an annual summary of data compiled for each drainage unit and arranged by individual storms, days, months, and by growing and dormant seasons.

The first effort at analysis and correlation will begin as soon as hydrologic data are available. This effort will be aimed at establishing rainfall-runoff relationships for each of the drainage units. The analysis will be brought up to date at the close of each season and will continue until enough years of observations are available to establish reliable trends. The period necessary to establish the rainfall-runoff relationships for each drainage unit will be known as the "period of standardization."

As indicated in an earlier section, before the period of standardization is complete, some drainage units will be subject to various watershed treatments. After treatment, the same observations will be made and compared with untreated areas during the period of standardization and the same general analysis made. New reaction curves and regression coefficients will be developed and as soon as these curves and coefficients are considered reliable, they will be compared to similar expressions derived for areas without treatment. These comparisons will be made by graphics in some cases and by statistical methods in others. Details of methods of comparison will be worked out when the data are available. Comparison with and without treatment between peak discharge rates, total water yield, and silt movement will be emphasized.

In order to provide a control for the analysis after treatment, certain drainages will remain untreated. New graphs will be drawn and coefficients calculated for the untreated drainages at the same time similar work is done for the treated ones. The new graphs and coefficients on the untreated units will be based only on data collected after the other drainages are treated. These graphs and coefficients will then be compared with similar ones for the same drainages derived from the analysis made at end of the period of standardization. Also these data will be compared with similar data for treated areas. These comparisons will provide a check on the reactions before and after the period of standardization on the same area and will provide the means of balancing, between areas, the effects of treatment against no treatment. The number of drainages which will remain untreated can be determined only after the analysis planned for the close of the standardization period is complete.

To summarize briefly, the analyses as planned for this study are grouped as follows: (1) Analysis of characteristics of individual drainage units without treatment; (2) comparison of characteristics of individual drainages with those of other drainages with different treatments; (3) determination of any changes in individual hydrologic characteristics caused by treatment.

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